

Industry Compliance Costs: What Would They Look Like in a Risk-Based Integrated Food System?

Laurian J. Unnevehr and Helen H. Jensen

Working Paper 01-WP 278

June 2001

**Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu**

Laurian J. Unnevehr is a professor in the Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign. Helen H. Jensen is a professor in the Department of Economics and head, Food and Nutrition Policy Division, Center for Agricultural and Rural Development, Iowa State University.

This paper was presented at the Resources for the Future conference, "Risk-Based Priority Setting in an Integrated Food Safety System: Current Knowledge and Research Needs," held May 23-24, 2001, in Washington, D.C. The authors acknowledge useful comments from David Hennessy. Partial funding support to H. Jensen was received from Cooperative State Research, Education, and Extension Service, National Research Initiative Agreement No. 98-35502-6604.

This publication is available online on the CARD website: www.card.iastate.edu. Permission is granted to reproduce this information with appropriate attribution to the authors and the Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa 50011-1070.

For questions or comments about the contents of this paper, please contact Helen Jensen, 578 Heady Hall, Iowa State University, Ames, Iowa 50011-1070; Phone: 515-294-6253; Fax: 515-294-6336; E-mail: hhjensen@iastate.edu.

Iowa State University does not discriminate on the basis of race, color, age, religion, national origin, sexual orientation, sex, marital status, disability, or status as a U.S. Vietnam Era Veteran. Any persons having inquiries concerning this may contact the Director of Affirmative Action, 318 Beardshear Hall, 515-294-7612.

Abstract

Current policies designed to improve food safety rely on regulation and market incentives. However, the mix of both private and public incentives to improve food safety and the dynamics of industry response to regulation make analysis of the costs of food safety complex. The paper provides an overview of costs of food safety regulation and control in recent literature for both pesticide and microbial controls and draws lessons for identifying cost-effective food safety approaches. Four lessons emerge concerning industry compliance costs. First, the distribution of costs is likely to be more important than market price effects. Second, regulation has an impact on long-run incentives to invest in new technologies or inputs and therefore may bias the nature of productivity growth. Third, an analysis of costs informs the choice among regulatory alternatives; allowing market adjustments to mitigate costs and improving upon existing market incentives is likely to be the most effective ways to reach public health goals. And fourth, a risk-based systems approach can be the best way to understand the costs, incentives, and risk outcomes resulting from alternative interventions. However this approach is made difficult by patchwork regulatory authority across the food chain and lack of data required for risk assessment.

Key words: economic costs of food safety, food safety, regulation, risk assessment.

INDUSTRY COMPLIANCE COSTS: WHAT WOULD THEY LOOK LIKE IN A RISK-BASED INTEGRATED FOOD SYSTEM?

Introduction

This paper, first presented at the Resources for the Future conference titled “Risk-Based Priority Setting in an Integrated Food Safety System,” is motivated by the observation that there may be missed opportunities for reducing risks in the food supply. In simplest terms, we want to identify food safety improvements that have the highest benefit-cost ratios. Other papers given at this conference examined emerging knowledge about the sources and incidence of foodborne risks. The purpose of our paper is to examine the costs of reducing those risks. We want to identify where food safety can be improved with the least burden on the food industry and, hence, the least cost to society.

In the case of food safety, the dynamics of industry response to regulation and the mix of both private and public incentives to improve food safety make analysis of regulatory costs more complex. This is because the market failure in food safety is never a complete failure. There are market incentives to improve food safety, and firms may adopt hazard control measures either to capture such incentives or in anticipation of more stringent regulation (Segerson 1999). Thus, the additional or marginal costs of regulation may be difficult to identify. However, we presume that the goal is improved food safety, whether achieved through regulation or through market incentives, and that the key is to identify those cost-effective opportunities, and then to identify the type of mechanisms that will encourage industry to take advantage of those opportunities.

The existing literature about the costs of compliance with food safety regulation is conditioned by the kinds of regulation and how long they have been in place. The regulations vary widely among hazards, food types, and stages of the production chain.

We divide our review into two parts, reflecting fundamental differences between regulation of chemical and microbial hazards. The literature on the costs of pesticide regulation reflects more than two decades of ex post experience with regulations initiated in the mid-1970s; it focuses mainly on the costs of regulation in crop production. The literature on microbial hazards is newer and arises in response to more recent regulatory initiatives in the 1990s; it focuses on the livestock product subsector.¹

The paper begins with an overview of the types of costs at issue in regulatory cost-benefit analysis, the types of economic modeling tools that have been used to measure costs, and the lessons from environmental economics regarding regulatory alternatives. We provide an overview of whether and how those tools have been applied to food safety regulation. Next, we summarize the findings from studies of pesticide regulation, and then we turn to studies of microbial regulation and draw lessons from each contribution to the literature. We focus on what is known about the structure of costs and what is known about the market incentives to improve food safety. We then turn to an examination of a systems approach to identification of cost-effective means of improving food safety as the most promising approach for identifying cost-effective changes to current practices. Finally, we conclude by offering some questions for future data collection and research.

Approaches to Measuring Social Costs

The Environmental Protection Agency (EPA) recently published guidelines for cost-benefit analysis of environmental regulation (U.S. EPA 2000). These provide a useful starting point for our review. Table 1, adapted from EPA's exhibit 8-2, gives examples of the kinds of costs that result from regulation; we have added some examples specific to food safety. These include the costs incurred by firms who must change production processes in some way to meet new standards, labeled real-resource compliance costs. Costs can be either fixed costs that require an investment over several years or variable costs that are incurred with each unit produced. Costs can be very concrete and easy to measure, such as the purchase of new equipment like the steam pasteurizer used in beef packing plants, or they can be more fuzzy, such as changes in labor organization to monitor

TABLE 1. Examples of social cost categories

Social Cost Category	General Examples	Food Safety Examples
Real-Resource Compliance Costs	Capital costs of new equipment Operation and maintenance of new equipment Change in production processes or inputs Maintenance changes in existing equipment Changes in input quality, such as skilled labor Changes in costs due to product quality; can be positive or negative	Steam pasteurizer Additional water needed for rinses Higher price of new pesticides More frequent cleaning Training of employees in HACCP procedures Lower quality of product with reduced pesticide use
Social Welfare Losses	Higher consumer and producer prices leading to changes in consumer and producer surplus Legal/administrative costs	Higher prices for crops with lost pesticide uses Higher prices for meat products Higher insurance costs against recalls
Transitional Social Costs	Firm closings Unemployment Resource shifts to other markets Transactions costs Disrupted production	Regional shifts in crop production Small meat processing plants shut down Reduced stock value due to recalls

Source: Adapted from Exhibit 8-2, in U.S. EPA "Guidelines for Preparing Economic Analysis" (2000). Note that Government Sector Regulatory Costs have been deleted, as these are beyond the scope of the paper.

temperatures. The simplest kind of cost analysis is simply an accounting for these costs within a static framework (e.g., so many plants pay so much extra per unit of output).

These direct costs to firms lead to other changes in markets, such as social welfare losses from higher consumer prices for meat products, or transitional social costs, such as possible firm closings due to the firms' inability to competitively meet standards (Just, Hueth, and Schmitz 1982). In measuring the latter two categories, both the distribution of real-resource costs and the adjustments to these costs are taken into account more fully. Adjustments may lead to lower costs over time as firms find more efficient ways to comply with standards, and understanding such adjustments is important for comparing

regulatory alternatives. Furthermore, the distribution of costs both between consumers and producers and among different kinds of producers and consumers will have important political economy implications.

Table 2 shows the kinds of modeling tools used by economists to measure compliance costs and their impacts on markets. Measuring direct compliance costs and their partial equilibrium impact on the market in question is usually the focus of regulatory analysis. Economists have extended this analysis in some cases to look more generally at impacts on several markets or at general equilibrium impacts in both factor and output markets. For example, Unnevehr, Gomez, and Garcia (1998) examined how HACCP costs would affect the three major meat product markets differently, due to differences in the incidence of costs and resulting substitutions in demand among beef, pork, and chicken. These substitutions reduced the total welfare cost of the regulation. Another example is the general equilibrium analysis of HACCP by Golan et al. (2000), who found that costs of implementation were almost fully passed through to households as a reduction in income (more than offset by a reduction in health care costs on the benefit side). The distribution of costs and benefits varied among household types, with the greatest net benefits going to households with children.

These kinds of modeling efforts are useful for illuminating the long-run effects of the regulation and their resulting costs. Such dynamics are important in determining incentives for innovation and compliance, and much of the economics literature has focused on the choice among regulatory approaches.

Choosing Regulatory Approaches that Result in Least-Cost Compliance

Government interventions can take many forms. We distinguish between direct command and control (CAC) interventions and information-based interventions that provide incentives for private market solutions (Litan and Nordhaus 1983; Ippolito 1984). Direct interventions include CAC standards for performance, for example, pathogen counts or residue tolerances for products at some stage of the marketing channel. Such standards require the product's quality to be monitored, usually based on sampling and

TABLE 2. Modeling tools and their uses in food safety cost analysis

Modeling Tools	Examples in Food Safety
Direct Compliance Costs	FSIS analysis for Pathogen Reduction Rule (USDA-FSIS 1996) estimated costs of training, changes in production processes for meat and poultry plants.
Partial Equilibrium Analysis	Roosen and Hennessy (2001) estimate the market effects of banning organophosphates for apples and compare welfare effects of different policies. Lichtenberg, Parker, and Zilberman (1988) estimate market effects of banning ethyl parathion in three tree crops and show distribution of social welfare costs among producers, consumers, and export markets.
Multimarket Model	Unnevehr, Gomez, and Garcia (1998) analyze impact of Pathogen Reduction Rule on different meat product markets and find that substitution in demand reduces social welfare losses.
General Equilibrium Analysis	Golan et al. (2000) use a Social Accounting Matrix to see general equilibrium effects from changes in medical expenses and meat processing costs as a result of HACCP in meat/poultry; they find that net benefits are higher among certain kinds of households.
Variable Cost Function	Antle (2000) estimates costs of improving quality and safety in meat plants based on past changes in input costs associated with higher product prices.
Risk Analysis Model	Narrood et al. (1999) examine points of intervention to reduce <i>E. coli</i> O157:H7 in beef packing plants and find rising marginal costs of control.
Linear Programming Model	Onal, Unnevehr, and Bekric (2000) use a regional supply and demand optimization model to estimate the impact of Salmonella restrictions on hogs delivered to packing plants and find reallocation of regional supply.

Source: Suggested by section 8.4 in U.S. EPA "Guidelines for Economic Analysis" (2000).

testing. In contrast, CAC processing standards achieve an improved final product by directly specifying procedures to be followed in production. Examples include worker re-entry restrictions for pesticide application or required sanitary operating procedures in meat plants. A third type of CAC approach is mandatory disclosure of information. Examples include requiring producers to provide information on any food safety processes they use, such as irradiation.

In contrast with CAC, incentive-based approaches are designed to induce either producers or consumers to identify and practice cost-effective methods that achieve improved food safety. Such interventions might include taxes on inputs with food safety risks, which would encourage their use only where marginal value product is highest; or information for consumers that allows them to evaluate and avoid a hazard; or facilitation of private contracting through public certification of products that meet a minimum safety standard.

The environmental economics literature demonstrates that there is a hierarchy among regulatory approaches from an economic efficiency perspective (Cropper and Oates 1992). The most desirable is an incentives-based approach that allows producers and consumers to choose the most efficient level of pollution. This is accomplished either by creating a market for the negative externality (e.g., tradable pollution rights), or by the application of optimal pollution taxes. Incentives-based approaches are preferable to CAC, which reduces efficiency by constraining market choice. Among CAC approaches, process standards are less efficient than performance standards. They specify how firms should achieve pollution reduction goals rather than specifying a performance standard and allowing firms to choose the least expensive process for achieving it (Besanko 1987). Setting performance standards, allowing choice of production methods, and fostering innovation to meet standards should allow greater efficiency in meeting a particular public health goal. Helfand (1991) demonstrated that setting a direct restriction on the level of pollution resulted in the highest level of economic returns and production efficiency among five different performance and process standards.

Alternative regulatory approaches to achieve the greatest risk reduction at the lowest cost have been proposed in the food safety literature, as we will discuss below. But

feasible incentives-based approaches differ between types of hazards. The presence of hazardous production inputs that are man-made, and are added as the result of producer decisions, can be influenced by incentives-based measures such as taxes. Naturally occurring hazards that can enter at any point in the food chain are expensive to test for and require different approaches (i.e., they cannot be taxed). The high cost of information that creates the market failure for microbial hazards also makes a performance standard impractical. We discuss this issue further in a subsequent section.

Costs of Pesticide Regulation

Pesticides are regulated by the EPA, which registers chemicals for particular use (i.e., for a specific crop), regulates application procedures, and sets tolerances for residues. Food safety is one of many criteria used in these regulations; environmental and farm worker safety are also important. It is widely recognized that food safety risks are very important in determining whether a particular use is allowed. The 1996 Food Quality Protection Act (FQPA) set a consistent standard for risks from pesticide residues in food, eliminating the double standard created by the previous division of regulation between the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) for crop residues and the Delaney clause of the Federal Food, Drug, and Cosmetic Act (FFDCA) for processed foods (Osteen 2001). The FQPA standard requires reasonable certainty that no harm will result to infants and children from aggregate exposure to all residues and also instructs that costs will not be considered in setting this standard. The FQPA requires reassessment of pesticide tolerances for all currently registered pesticides, and the EPA has given priority to organophosphates because of their importance in children's dietary exposure. Organophosphates are widely used in field crops and in fruits and vegetables important in children's diets (e.g., apples) (Osteen 2001). This potential loss of pesticides that are currently widely used lends some urgency to examining the lessons from past analysis of pesticide regulation.

Three themes emerge from the pesticide literature:

1. there are small marginal costs to banning any particular use, but these rise as more uses are banned and fewer substitutes are available;

2. the practice of banning particular uses makes regulation more costly and the same benefits could be achieved at lower cost through different regulatory mechanisms that allocate pesticide uses where they have highest value; and
3. the high costs of registration for new pesticides have discouraged development of new alternatives.

We examine each theme below.

The benefits from use of pesticides in crop production can be interpreted as both significant and insignificant, depending on the standard being used. Teague and Brorsen (1995) report that the ratio of the marginal value product of pesticide use to pesticide price in three states is much greater than one, indicating the strong profits attached to pesticide use. Gren (1994) found that a hypothetical 50 percent reduction in pesticide use in Sweden would result in a 6 percent reduction in farm incomes. Hanson, Lichtenberg, and Peters (1997) find that organic grain production in the mid-Atlantic can achieve yields comparable with conventional agriculture but requires more family labor and management, whose value is difficult to quantify. Thus, while pesticides are found to be profitable to use, the estimated costs of banning or restricting their use depend on the particular crop and the assumptions made.

Zilberman et al. (1991) and Osteen (1994) summarize the literature regarding the costs of banning pesticide uses and provide a number of insights about why results of regulatory cost estimates can vary widely. First, the estimated costs of banning a pesticide use depend crucially on the availability of substitute chemicals for that use. As entire classes of pesticides are restricted or canceled, there are fewer substitutes available, and the cost of the restrictions rises (Roosen and Hennessy 2001). Second, a major effect of banning a pesticide is to shift production to regions with less need for pesticide use. If this supply response is fairly elastic, then there is less impact on market prices of the crop, but there is also a clear regional redistribution of farm income (Lichtenberg, Parker, and Zilberman 1988). In particular, agriculture in the southern United States is more likely to be impacted by pesticide restrictions than are other regions, as the agro-climatic conditions favor pests (Osteen 1994). Third, market price impacts of pesticide bans depend upon the elasticity of supply response, including the availability of substitutes and

the ease of shifting production to other regions. When the crop is traded, the price effects in domestic markets are mitigated by changes in exports or imports, but the higher costs for domestic producers make them less competitive in world markets (Zilberman et al. 1991). Fourth, research and development to find substitutes or safer alternatives substantially reduces the cost of regulation in the long run (Osteen 1994).

Many economists have pointed out that the use of pesticide bans is an economically inefficient way of reducing risks from pesticides (Gren 1994; Zilberman et al. 1991; Zilberman and Millock 1997; Swinton and Batie 2001). Regulation that bans pesticide use often is more costly than other approaches that lead to similar reductions. Banning the use of a pesticide on a crop does not necessarily reduce use where its use causes the greatest harm. Equivalent or greater risk reductions could be achieved at lower cost by alternative policies that allocate pesticide risks toward their highest value uses. Such policies might include pesticide taxes, which could vary by crop or location of use, or tradable rights to use pesticides, which producers could buy and sell. This would allocate pesticide use toward crops and regions where it has highest marginal value product while still achieving target average residues. Another alternative policy would be to set residue limits for food products rather than for crops, in order to create incentives to directly address food safety risks (Swinton and Batie 2001). This would encourage a “systems” approach to reducing residues. Unfortunately, such alternatives are not under consideration, so the current review of registrations under FQPA may result in widespread bans and higher costs of production for many crops.

A third theme in the pesticide literature is that regulation has discouraged the development of new chemicals and sometimes reduced the availability of existing chemicals. The high cost of supporting re-registrations for some pesticides discourages their support by manufacturers, especially for so-called minor uses (i.e., crops with limited acreage) (Osteen 1994). Ollinger and Fernandez-Cornejo (1995) estimate that development of a new pesticide takes 11 years and can cost manufacturers between \$50 and \$70 million. They also found that regulation encourages the development of less toxic pesticide materials and of biological pesticides as an alternative to chemical pesticides. But regulation discourages new chemical registrations, encourages firms to

abandon registrations for minor crops, and favors large firms over smaller ones. The emphasis on reducing crop residues to meet a food safety standard also means that newer chemicals decay more rapidly but may also be more toxic to farmworkers (Rola and Pingali 1993). Thus, regulation creates incentives that influence the long-run pace and direction of new technology development.

The three themes in the pesticide literature provide important lessons. First, the redistribution effects among producing regions are likely to be more important than direct price effects in crop markets. Second, the choice of regulatory instruments has important implications for the costs of regulation. Third, the design of regulation influences long-run incentives for the development of new technologies. These lessons have some application in the emerging regulation of microbial hazards.

Costs of Regulating Microbial Hazards

Growing scientific awareness of the importance of foodborne pathogens led to new regulatory initiatives in the 1990s. Advances in public health (e.g., improved information through faster and more sensitive tests for pathogens as well as better epidemiology) permitted improved surveillance of foodborne illnesses, linked specific foods and companies with pathogen contamination, and identified known human illnesses as complications of acute foodborne infections. New federal initiatives to address microbial hazards include HACCP (Hazard Analysis and Critical Control Points) regulations in seafood, meat and poultry, and fruit juices (U.S. FDA 1995; USDA-FSIS 1996; U.S. FDA 2001); the development of Good Agricultural Practice (GAP) guidelines for produce (U.S. FDA 1998); and regulations regarding shell egg handling (U.S. FDA 2000). As these new regulations and guidelines developed, a literature emerged to evaluate the impact on the food industry. Because experiences and data collection are recent, this literature is still evolving. It is more difficult to establish “lessons” in this area than in the case of pesticides.

In contrast to pesticides, which are man-made substances added during production, microbial hazards are naturally occurring organisms. Often, they can enter food products throughout the food supply/production chain, and, once present, they can grow in

numbers. Therefore control at one level does not assure control at subsequent levels; and lack of control at one level has consequences for the following stages in the food chain. This makes hazard control and the design of regulation more complex; it also complicates economic analysis of the costs of control.

One issue debated in the 1990s is the nature of HACCP as a regulatory standard. HACCP was initially developed in the 1960s by private industry as a management tool (Mazzocco 1996). As such, it provides efficiency in managing processes when the hazards and standards are clearly defined. That is, it can reduce the costs of testing, and of reworking or disposing of spoiled products, by preventing hazards and contamination. The focus on critical control points can lead to redesign of the production process to achieve control more efficiently. However, HACCP systems clearly entail costs, which are justified in private industry when there are market incentives for assuring a particular standard of safety.

The costs of monitoring and testing are important for naturally occurring hazards, and are a motivation for a HACCP approach (National Research Council 1985). The high costs of obtaining information (i.e., testing for microbial hazards *ex post*) make it more economical to emphasize prevention and monitoring of easily accessible indicators, in either private or public efforts to reduce such hazards (Unnevehr and Jensen 1996; MacDonald and Crutchfield 1996). In the 1990s, HACCP was mandated by federal regulation for firms in the seafood and meat/poultry industries, and in 2001 for the fruit juice industry. Specific HACCP plans are not mandated; under all three regulations, individual firms are to develop plans that are relevant to their particular product mix and plant situation. These plans are then reviewed and approved by regulators. In the meat/poultry and fruit juice regulations, pathogen testing and reductions in pathogens are required. In the case of fruit juice, pathogen reduction is to be achieved through the use of a technology that meets a five log pathogen reduction performance standard reduction of generic *E. coli*.

The flexibility in this type of regulation means that it is difficult to estimate its costs *ex ante*. For example, it is unclear what kind of changes in production processes might result from HACCP implementation. The flexibility in approach does not eliminate plant

heterogeneity in terms of pathogen levels, which is one reason to also specify pathogen reductions, as in the meat/poultry HACCP regulation (MacDonald and Crutchfield 1996). Thus, the nature of the HACCP regulation is unclear: Is it a performance standard or a process standard? Unnevehr and Jensen (1999, 1996) and Antle (2000) describe the Pathogen Reduction Regulation in meat and poultry as a combination of performance and process standards. Helfand's (1991) analysis provides insights regarding use of mixed standards. In her terminology, this regulation combines the mandated use of a pollution control technology (HACCP) with a standard on pollution per unit of output (percentage of samples with pathogens). This combination will tend to maintain high levels of output but will reduce economic returns more than would a direct restriction on the level of pollution. But this result depends on assumptions about the effect of the control technology on output and use of other inputs. For example, if HACCP does not contribute to production (changing only fixed costs with no change in marginal cost), then its imposition is equivalent to a direct restriction on the level of contamination. Thus, whether HACCP allows for efficient firm response to regulation is still unclear and will depend on how well it helps firms to meet associated pathogen standards and whether it leads to significant changes in the variable costs of production.

Because *ex ante* costs are difficult to estimate and controversial in the food industry, there has been considerable interest in estimating HACCP costs as the regulations are implemented. For example, during the discussion period of the HACCP rule for meat and poultry, Texas A&M University released an alternative cost estimate that showed much higher initial costs for industry than the Food Safety and Inspection Service (FSIS) estimate (see Crutchfield et al. 1997 for a review and comparison). A number of studies have been undertaken of HACCP (see collection in Unnevehr 2000), and it is now possible to make some *ex post* comparisons and generalizations, although more definitive answers will only emerge after longer experience. Studies of the costs of pathogen reduction show that both the FSIS and the Food and Drug Administration (FDA) underestimated the costs of HACCP in their *ex ante* analyses. For example, Jensen and Unnevehr (2000) estimate that modifications of pork slaughter processes to reduce pathogens would cost \$0.20 to \$0.47 per carcass, substantially more than the FSIS

estimate of \$0.0056 for process modifications (Crutchfield et al. 1997). Antle (2000) analyzed past costs of quality improvement in the meat industry and extrapolated that a 20 percent improvement in safety would have additional costs in the range of \$0.01 to \$0.09 per pound of product, which is several times larger than the FSIS estimates of less than \$0.001 per pound. Colatore and Caswell (2000) found that the FDA underestimated the cost of HACCP in seafood plants, particularly the costs of plan design, training, corrective actions, and sanitation.

It is clear that the marginal costs of pathogen reduction are increasing and that complete control is quite costly. For example, Jensen, Unnevehr, and Gomez (1998) found that pathogen control marginal cost curves are steeply increasing in both beef and pork. Costs rise from \$0.20 to \$1.40 per beef carcass and from \$0.03 cents to \$0.25 per pork carcass as pathogen reduction increases from one log to four logs.² Figure 1, from Jensen, Unnevehr, and Gomez (1998), shows costs and pathogen reductions for pork carcasses with different combinations of water rinses and sanitizing sprays. Costs increase from \$0.03/carcass for a low temperature (25°C) water rinse to more than \$0.20 for the combination of hot (65°C) water rinse and sanitizing spray, which achieves the greatest pathogen reduction. Figure 1 also shows that a cold water rinse plus sanitizing spray is more efficient than the 55°C rinse and spray, which lies inside the cost frontier. Narrod et al. (1999) find rising costs of *E. coli* control in beef packing plants; costs rise from \$0.05 to \$0.45 per carcass as contamination is eliminated from 30 percent to 100 percent of production. Both of these studies emphasize that there is a frontier of efficient control technologies and technology combinations that provides least-cost pathogen reduction.

Plants are not yet required to implement high levels of pathogen control (or elimination); the regulation requires that plants reduce their incidence to the pre-regulation average for the animal species. Thus, to date, actual costs incurred by meat and poultry firms likely are still small relative to total costs and product prices. They may be around 1 to 2 percent of current processing costs (Jensen and Unnevehr 2000) and thus are unlikely to lead to major increases in meat prices.

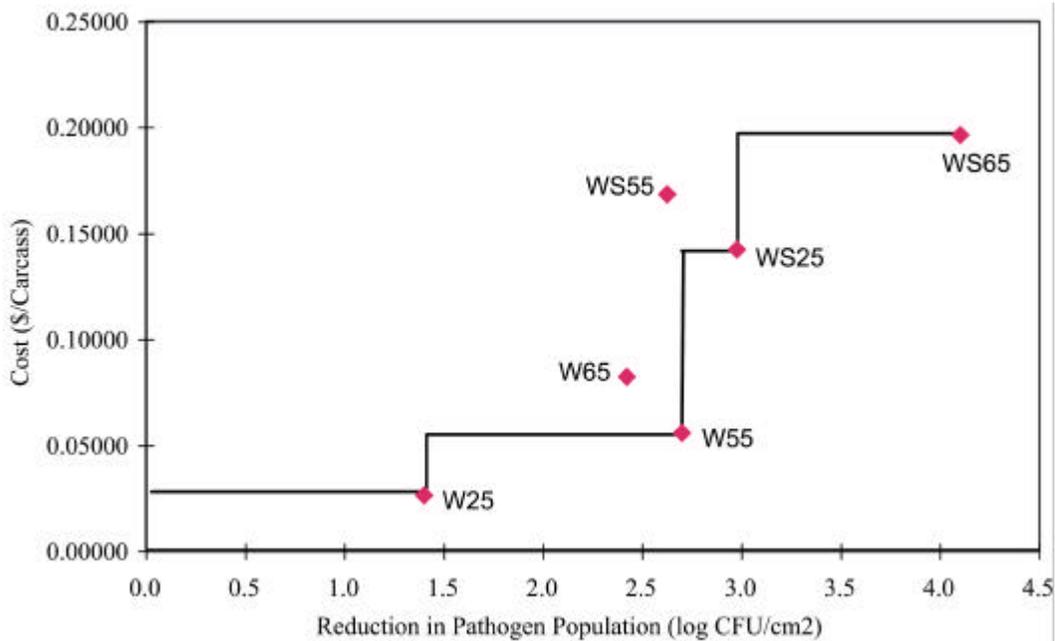


FIGURE 1. Total enterics reduction for different technologies in pork

While costs are small on average, they may still be enough to shift the distribution or scale of production at the margin. In both the seafood and meat/poultry industries, the impact of HACCP on small firms was an important consideration in the design of regulation. Both the meat/poultry and the fruit juice HACCP regulations were phased in with a longer adjustment period allowed for small plants. First time implementation of HACCP requires large up-front investments in developing and implementing the HACCP plan; these costs are lower on a per unit basis for larger food processors (Hooker, Siebert, and Nayga 2000; Nganje and Mazzocco 2000). Therefore, small firms' costs rise proportionally more than large firms' with the implementation of HACCP, which may put them at a competitive disadvantage in the market. Furthermore, large firms frequently have more in-house resources at their disposal for design and implementation (e.g., meat scientists on staff; diagnostic labs) and therefore have lower transactions costs in implementing a HACCP plan. Some small firms might be expected to go out of business as a result of higher relative costs.³ Also, the need to have separate HACCP procedures for different products may also force small plants to drop some product lines (Hooker, Siebert, and Nayga 2000; Nganje and Mazzocco 2000). However, the ultimate impact on

industry structure would be difficult to assign to food safety regulation alone, due to the high rate of plant closings and other forces contributing to firm consolidation (MacDonald and Crutchfield 1996).

Another difficulty in assigning costs to regulation is that firms face a mix of market and regulatory incentives in adopting food safety measures. Certain markets increasingly demand evidence of hazard control from their suppliers, and this provides motivation beyond the minimum prescribed by regulation. Martin and Anderson (2000) report widespread adoption of HACCP and/or food safety control procedures among U.S. food processing firms. Almost 70 percent of large plants have a HACCP plan for at least one product; a majority of these firms also carry out food safety procedures associated with HACCP, such as monitoring temperatures of raw ingredients. Colatore and Caswell (2000) found that most seafood plants implemented more extensive and costly HACCP plans than required by regulation, because they found other motivations to do so. The implication is that market incentives are driving firms to adopt food safety practices. This then raises the question of what additional food safety is provided by regulation and what additional costs can be assigned to this improvement.

Another issue in assessing costs is whether HACCP regulations in the processing industry will lead to greater demand for hazard reduction in farm-level production. In many ways, HACCP reduces communication costs about the provision of safety. Fewer studies have been conducted at the farm level because there has been little regulatory activity, but the application of regulation to one part of the food chain can create incentives that are passed back to suppliers through the marketplace. An important theme from the European literature is that food processors and retailers are increasingly looking for assurances of food safety from their suppliers, creating incentives for improved safety throughout the food chain. In the United Kingdom, the passage of “due diligence” laws has forced food retailers to ask their suppliers for certification of hazard management (Henson and Northen 1998), and ISO 9000 methods for certification have been applied in the UK meat sector (Zaibet and Bredahl 1997).

In the United States, such contracts tend to be motivated entirely by market incentives and there is less reported evidence that regulation has played a role. In the

meat subsector, fast-food services specify food safety standards in their contracts with suppliers (Burgdorfer 2001). Suppliers of produce to major U.S. supermarket chains must certify food safety practices, and this is true for international as well as domestic producers (Calvin and Cook 2001). In the produce market, this certification has been facilitated by the use of FDA's GAP guidelines.

There are a few studies at the farm level of hypothetical costs of adopting measures to reduce microbial hazards. Onal, Unnevehr, and Bekric (2000) examined the costs of restricting *Salmonella* contamination in hogs delivered to packing plants. Because there are differences in contamination levels by farm size and region, such restrictions would alter the regional distribution of production and increase costs for the system as a whole. Hayes et al. (1999) use Sweden's experience with banning antibiotic use in pork production to draw lessons for a possible ban in the United States. They find that such a ban would tend to reward producers who are already managing productivity and quality well. Wang et al. (2000) find similar results for control of toxoplasmosis in pork. Confinement production would have a slight cost advantage if control of this infection became mandatory. These findings reinforce the general theme that regulation can influence industry structure and may influence the regional distribution of production at the farm level.

An important structural issue that has not received much analysis is the outcome from new standards in markets with significant international trade. As trade in food products grows, the interaction of trade and regulation becomes more important. Regulations should apply equally to both domestic and imported foods. For example, seafood exports to the United States (which account for more than one-half of supply) should be processed under HACCP plans just as in domestic plants. However, enforcement of equivalent standards for foreign producers may be limited by the resources devoted to inspection and monitoring.

The presence of imports or exports will influence market response to regulation and the incentives for domestic food safety improvement. Worth (2000) calculated the reputation cost of a food safety outbreak from strawberries for domestic producers. When

there are different supply sources, it is difficult for domestic producers to capture all of the benefits of safety improvement.

The microbial hazards literature raises several themes but does not yet have well-documented results. These themes include the difficulties of assessing HACCP costs and impacts due to the flexibility inherent in HACCP approaches; the likely rising marginal cost of food safety improvement; the presence of both private and regulatory incentives for improving food safety; and the likely structural implications of food safety regulation or market incentives for firm size, supply chain coordination, and international competitiveness.

In addition, there are several important questions raised in the literature, which will require multidisciplinary research to address in the future. One such question is what kind of regulatory approaches can best utilize incentives to increase food safety at least cost. In particular, can an enforceable standard be set for a naturally occurring hazard that is expensive to test for? If HACCP is flexible in implementation, then what improvement in food safety is actually achieved? Furthermore, given the difficulty of mapping pathogen reductions at one point in the food supply chain to illness outcomes in consumers, another question is how best to compare benefits and costs from HACCP regulations. All of these questions arise from the nature of microbial hazards and of process controls and lead us to explore whether a systems approach is the best way to find cost-effective improvements.

Looking at the Entire Food System

Greater attention to food safety highlights the integrated nature of the food production system. Assignment of costs and changes in the nature of costs depend on understanding this integration. As discussed in the preceding sections, the nature of a food safety risk depends on the product and type of contamination. Some hazards, such as pesticides applied at the farm, enter the food chain system in early stages. Processing and handling affect the hazard levels on the food product as it goes through the system until it reaches the final consumer. In contrast, microbial hazards are naturally occurring; contamination can enter the food production system at any stage, and unless it is

eliminated at one stage in the production process, it can present problems at later stages of production. The controls of risks are linked across stages.

Probabilistic Scenario Analysis (PSA) and closely related Fault Tree Analysis (FTA) are tools used to account for multiple events and the probability of any event occurring in the food production system (Roberts, Ahl, and McDowell 1995). The PSA makes use of information on links in the food chain and events that may compromise the safety of the food: the type of hazard, the different ways it enters the food chain (e.g., the specific link and linkages), and the full list of other expected events. The “links in the food chain” are specialized, self-contained activities that are connected to events that determine the human health outcome. An “event tree” summarizes this information.

One example is the occurrence of *E. coli* O157:H7 in cattle at slaughter (Roberts, Ahl, and McDowell 1995). Cattle shipped to slaughter may carry threshold levels of the pathogen. The probability that *E. coli* O157:H7 contamination will occur in cattle at slaughter depends on whether (and how likely it is that) cattle carry the pathogen and whether the pathogen is detected at entry to the slaughterhouse. The slaughter operation is one “link” in the food chain or processing system. Later stages in the system occur through processing and fabrication, distribution and transport, wholesale/retailing, and finally to the consumer level. In the food production system, each of these stages offers potential for contamination or recontamination. The PSA or FTA approach takes into account various linkages in the food system at a point in time, probabilities of occurrence, and all associated probabilities of failure (or, alternatively, effectiveness of control). The high-risk (or most likely) pathway becomes a likely candidate for control analysis.

In principle, information on the probabilities and paths in the production system can be used to assign expected costs to various control options and to identify the most cost-effective mitigation options. By identifying combinations of lowest-cost interventions to achieve various levels of improved safety, the analyst can articulate optimal strategies. This approach combines risk outcomes and economic cost criteria to identify dominant solutions (McDowell et al. 1995). The outcome and cost-dominance approach underlies the recently published models that identify the cost-efficient combinations of interventions when used to evaluate beef processing (Jensen, Unnevehr, and Gomez

1998; Narrod et al. 1999) and pork processing (Jensen and Unnevehr 2000). In principle, however, such prescriptive economics is more likely to depend on a combination of methods from decision theory, risk analysis, and economics (McDowell et al. 1995).⁴ Although the PSA/FTA approach describes system linkages in food production, it gives little guidance for identifying strategies to reduce hazards across the whole system because it fails to account for incentives that may lead to different behaviors and choices of technologies and controls among stages.

Food safety failures often stem from problems that are systemic in nature. The systemic failures occur in production systems characterized by interconnected stages in production and inputs, and this interconnectivity gives rise to the technological potential for failures. At the same time, incentive problems provide the economic potential for failures (Hennessy, Roosen, and Miranowski 2000; Narrod et al. 1999). The mixing of meat from a number of farm sources at the packer, processing, or intermediary levels illustrates both the interconnectivity in inputs and stages of production and incentive problems. Ground meat may come from many different animal/farm sources. Problems that occur on the farm, or in handling of a single animal, can easily spread through the food product in the plant. Furthermore, when intermediaries co-mingle beef from several sources, failure in one large batch can quickly spread to consumers in a large geographic area (Hennessy and Roosen 2000). Testing of a product at different stages is often difficult (and rapid tests are not available). Incentive problems occur because it is difficult for packers to reward farmers for caretaking, and farmers have no incentive to take additional care in production or transport to reduce the likelihood of problems at the packer level; nor do packers that sell the product to intermediaries that co-mingle beef from several sources have market incentive to adopt technologies that reduce pathogens in the plant source.

Interconnectivity gives rise to complementarities in input use (care in one area may increase the likelihood of care given in other aspects of production). The presence of complementarities among activities means that there may be benefits that arise from complementary activities that cannot be assigned to the marginal product of any individual activity (Goodhue and Rausser 1999). A change in the cost of one activity is

likely to move a whole cluster of complementary activities in the food production system. This may explain Colatore and Caswell's (2000) finding that seafood plants implemented control measures beyond the minimum mandated by regulation.

A packer facing the problem of downstream risks might choose to provide incentives to input suppliers for documented production practices. With complementarity in inputs, a change in the price of one practice (e.g., an incentive paid by the packer firm for feeding withdrawal) is likely to bring along other complementary practices, such as more careful tracking of transportation practices. An alternative to payment of incentives to input suppliers is to purchase control of the input supply (i.e., shift ownership and control of production or transport to the packer firm). In this case, increasing vertical coordination can redistribute the risks and rents associated with reduced risk.

The complexity of most food production today suggests the importance of considering food safety problems from a systems perspective. A good example of such an approach is the action plan developed by FDA, FSIS, and Animal and Plant Health Inspection Service (APHIS) to eliminate *Salmonella enteritidis* (SE) illness due to eggs (President's Council on Food Safety 1999). Underlying the action plan was a risk assessment model. The risk assessment model indicated that multiple interventions would achieve more reductions in SE illness than would a single point of intervention. The use of a risk assessment approach allowed combining information about the risk, sources of risk, potential for controls throughout the egg production system, and identified potential sites for intervention. The identified advantage of multiple interventions suggested following a broadly based policy approach across stages of production, instead of focusing on a single stage of production.

Figure 2, from the President's Council on Food Safety (1999), shows the stages of egg production and the agencies responsible at each stage. The action plan identifies a set of activities at each stage. Producers and packer/processors can choose between two strategies designed to give equivalent performance in terms of reduction in SE at the egg production and packer/processor stages. The first strategy (Strategy I) focuses efforts at farm-level testing and egg diversion; the second strategy (Strategy II) directs more

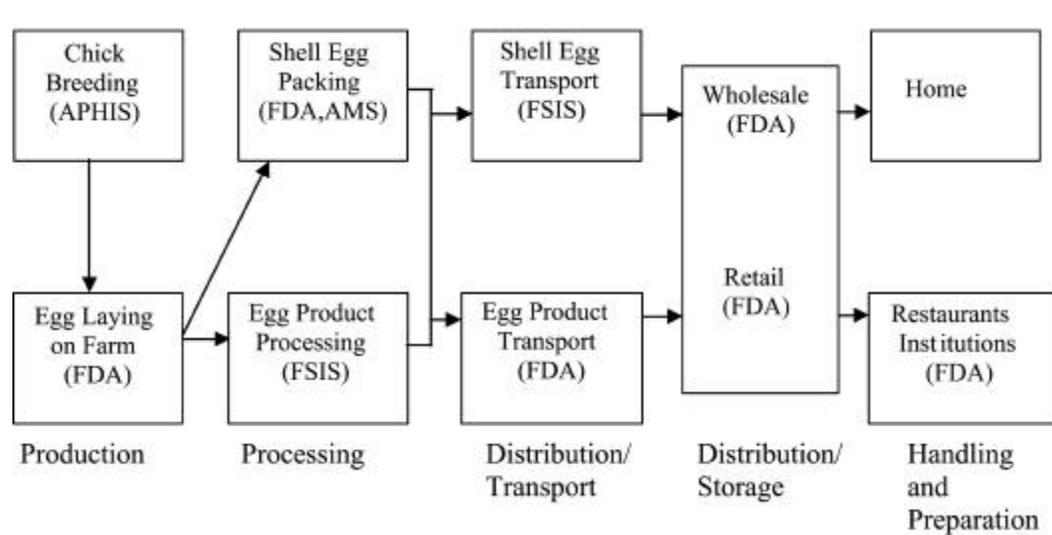


FIGURE 2. Egg safety from production to consumption

resources to the packer/processor level and includes a lethal treatment, or “kill step” (and HACCP plan), at this stage. Both strategies include common features of regulatory presence on the farm (e.g., control of chicks from SE flocks) and at the packer/processor (e.g., mandated prerequisite programs of sanitary controls, washing). In addition to the interventions at production and packer/processor stages, the action plan sets refrigeration standards for the distribution and retail stages to ensure that reductions in SE are preserved at later stages in the food supply chain. The flexibility offered to the industry in choosing between strategies for control at the producer and packing/processor levels allows for development of incentive structures consistent with the overall objectives of eliminating SE illnesses. The action plan explicitly identifies performance measures (output standards) to be used (e.g., reduced illnesses, SE isolates, and number of SE outbreaks) and the responsible agency for each stage in the farm-to-table continuum.

Although the action plan for SE in eggs is still early in its implementation, it provides a good example of how a system-wide approach might be used. In this case, the systems approach facilitated the development and coordination of public and private strategies across the egg production system. The risk assessment model focuses on the desired public health outcome. The plan allows industry flexibility in developing and coordinating incentives across stages (production and processing/packing). Costs

incurred under this systems approach are likely to be smaller than when interventions focus on only one point in the food chain. This is an example of how risk assessment can interface with economic incentives, and it will be interesting to review the plan's impact on *Salmonella* control costs in a few years.

Conclusions Regarding Lessons and Future Directions for Research

There are four lessons we take away from this review of the literatures on pesticides and microbial hazards. The first lesson is that the distribution of costs (and resulting transitional costs) is likely to be more important than market price effects, at least for the regulations imposed up to this point. That is, food prices and availability for consumers are rarely the issues in regulation impacts. This is partly because supply can be shifted to different regions, plants, or even countries. It is also partly a result of past balancing of costs and benefits in making regulatory decisions. The structural impacts that lead to painful economic adjustments, as when production becomes infeasible in a particular region or when small firms in rural areas go out of business, are more important than market price impacts. A second lesson is that regulation has an impact on long-run incentives to invest in new technologies or inputs and therefore is likely to bias the nature of productivity growth. Measuring these long-run costs and benefits to society is much more difficult, because the counterfactual cannot be observed; however, these impacts are important to consider in the design of new regulation. This leads to our third lesson: the most important reason to analyze costs is to choose among regulatory alternatives. Greater benefits can be achieved more quickly at lower cost to society with incentives-based measures. Allowing market adjustments to mitigate costs and improving upon existing market incentives will be the most effective ways to reach public health goals. Our fourth lesson is that a risk-based systems approach can be the best way to understand the costs, incentives, and risk outcomes resulting from alternative interventions. This approach is difficult due to patchwork regulatory authority over different parts of the food chain and due to the data required for risk assessment.

Given these lessons from the literature, what can we say about the need for research and data? Looking to the future, we can see increased attention to addressing microbial hazards, rising food safety standards, growing international trade of food products, emerging technologies that reduce information costs, and increased feasibility of public and private coordination. In that context, we have identified four areas for research and data collection. The first and most important is to adapt the conceptual framework for evaluating alternative regulatory instruments to the specifics of regulating risks from microbial hazards. We do not have any analysis of how alternative regulatory actions would alter microbial hazard reduction outcomes, incentives, innovation, or benefit/cost ratios. Some differences in implicit standards already exist which could provide data for analysis, such as the product specifications imposed on beef purchased for school lunches. Given the strong market incentives evident in microbial food safety, it will be important to identify the appropriate role for government intervention so as not to introduce inefficiencies through regulatory overkill. The second, and related, area for research is the impact of new information technologies (e.g., rapid tests, genetic fingerprinting) on the market failure in microbial food safety. We need to understand how such technologies can aid in setting performance standards and in helping the food industry to respond more efficiently to standards. A third area for economics research is to examine the interaction of higher domestic standards with international trade. The distributional effects of regulation are more likely to be between domestic production and trade in the future. We need to know whether standards are applied in equivalent ways to domestic production and imports and to better understand U.S. comparative advantage in the production of safety attributes. Finally, a fourth area for future research is the interdisciplinary field of risk assessment applied to the entire food chain, which is still in its infancy. The SE risk assessment model for shell eggs and egg products illustrates the ability to assemble and analyze data across various stages of the food production system in order to achieve a science-based plan for food safety improvements. Because such research requires expensive data collection, efforts in this area should be directed toward the most important public health risks.

Our concluding comment is that economic analysis will be particularly useful for evaluating future alternatives for microbial hazards, because it is directed toward understanding system-wide impacts and adjustments. We may not yet know what industry costs look like in a risk-based integrated system. But economists can help to identify the kind of system that will foster innovation and efficiency in meeting public health goals.

Endnotes

1. There are also a few studies of the cost impacts of regulations regarding growth hormones or antibiotic use in livestock production; we did not find any studies of mycotoxin or toxic waste regulatory costs (as they relate to food safety) in the published literature.
2. One of the difficulties of evaluating interventions to control pathogens is that their effectiveness is generally measured under laboratory conditions where samples are intentionally inoculated with high levels of pathogens. In meat processing plants, levels of contamination are low, and many more samples would be needed to assess the effectiveness of a technology.
3. Another source of higher costs might be greater sanitation and process control deficiencies in small plants. Ollinger (2000) found that such deficiencies were negatively associated with firm and plant size.
4. Given the demand for data, application of probabilistic models is more realistic when confined to examining particular hazards and linkages, in contrast to examining the entire food production system.

References

- Antle, J.M. 2000. "No Such Thing as a Free Safe Lunch: The Cost of Food Safety Regulation in the Meat Industry." *American Journal of Agricultural Economics* 82(May): 310-22.
- Besanko, D. 1987. "Performance Versus Design Standards in the Regulation of Pollution." *Journal of Public Economics* 34(October): 19-44.
- Burgdorfer, B. 2001. "Top US beef packers can meet McDonald's BSE deadline." *Reuters and Fsnnet*, March 15.
- Calvin, L., and R. Cook. 2001. "U.S. Fresh Fruit and Vegetable Marketing: Emerging Trade Practices, Trends, and Issues." U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No 795, Washington, D.C.
- Colatore, C., and J.A. Caswell. 2000. "The Cost of HACCP Implementation in the Seafood Industry." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St. Paul, MN: Eagan Press, pp. 45-68.
- Cropper, M.L., and W.E. Oates. 1992. "Environmental Economics: A Survey." *Journal of Economic Literature* 30(June): 675-740.
- Crutchfield, S.R., J.C. Buzby, T. Roberts, M. Ollinger, and C-T. Jordan Lin. 1997. "An Economic Assessment of Food Safety Regulations: The New Approach to Meat and Poultry Inspection." U.S. Department of Agriculture, Food and Consumer Economics Division, Economic Research Service, Agricultural Economic Report No. 755, Washington, D.C., July.
- Golan, E.H., S.J. Vogel, P.D. Frenzen, and K.L. Ralston. 2000. "Tracing the Costs and Benefits of Improvements in Food Safety: The Case of the Hazard Analysis Critical Control Point Program in Meat and Poultry." U.S. Department of Agriculture, Economic Research Service, Agricultural Economics Report No. 791, Washington, D.C., October.
- Goodhue, R.E., and G.C. Rausser. 1999. "Value Differentiation in Agriculture: Driving Forces and Complementarities." In *Vertical Relationships and Coordination I: The Food System*, edited by G. Galizzi and L. Venturi. Heidelberg, Germany: Physica-Verlag Publishers, pp. 93-112.
- Gren, I-M. 1994. "Cost Efficient Pesticide Reductions: A Study of Sweden." *Environmental and Resource Economics* 4(3, June): 277.
- Hanson, J.C., E. Lichtenberg, and S.E. Peters. 1997. "Organic Versus Conventional Grain Production in the Mid-Atlantic: An Economic and Farming System Overview." *American Journal of Alternative Agriculture* 12(1): 2-9.

- Hayes, D.J., H.H. Jensen, L. Backstrom, and J. Fabiosa. 1999. "Economic Impact of a Ban on the Use of Over the Counter Antibiotics in U.S. Swine Rations." *International Food and Agribusiness Management Review*. Special Issue: "Private Sector Management of Food Safety." First published as CARD Staff Report SR-90 (December 1999), Center for Agricultural and Rural Development, Iowa State University.
<http://www.card.iastate.edu/publications/texts/99sr90.pdf> (April 2001).
- Helfand, G.E. 1991. "Standards Versus Standards: The Effects of Different Pollution Restrictions." *American Economic Review* 81(June): 622-34.
- Hennessy, D.A. and J. Roosen. 2000. "Systemic Failure in the Provision of Food." Journal paper No. J-19047 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 3463 and supported by Hatch Act and State of Iowa funds.
- Hennessy, D.A., J. Roosen, and J.A. Miranowski. 2000. "Leadership and the Provision of Safe Food." Journal paper No. J-18856 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 3463 and supported by Hatch Act and State of Iowa funds. (*American Journal of Agricultural Economics*, forthcoming).
- Henson, S., and J. Northen. 1998. "Economic Determinants of Food Safety Controls in Supply of Retailer Own-Branded Products in United Kingdom." *Agribusiness* 14: 113-26.
- Hooker, N.H., J. Siebert, and R.M. Nayga, Jr. 2000. "The Impact of HACCP on Costs and Product Exit: Evidence from Meat Processors in Texas." Abstract. *Journal of Agricultural and Resource Economics* 25(2): 727.
- Ippolito, P.M. 1984. *Consumer Protection Economics: A Selective Survey Empirical Approaches to Consumer Protection Economics*. Edited by P.M. Ippolito and D.T. Scheffman. Bureau of Economics, Federal Trade Commission, Washington, D.C., April.
- Jensen, H.H., and L.J. Unnevehr. 2000. "HACCP in Pork Processing: Costs and Benefits." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St. Paul, MN: Eagan Press, pp. 29-44.
- Jensen, H.H., L.J. Unnevehr, and M.I. Gomez. 1998. "Costs of Improving Food Safety in the Meat Sector." *Journal of Agricultural and Applied Economics* 30(1, July): 83-94.
- Just, R.E., D.L. Hueth, and A. Schmitz. 1982. *Applied Welfare Economics and Public Policy*. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Lichtenberg, E., D.D. Parker, and D. Zilberman. 1988. "Marginal Analysis of Welfare Costs of Environmental Policies: The Case of Pesticide Regulation." *American Journal of Agricultural Economics* 70(November): 867-74.
- Litan, R.E., and W.D. Nordhaus. 1983. *Reforming Federal Regulation*. New Haven, CT: Yale University Press.
- MacDonald, J.M., and S. Crutchfield. 1996. "Modeling the Cost of Food Safety Regulation." *American Journal of Agricultural Economics* 78(December): 1285-90.
- Martin, S.A., and D.W. Anderson. 2000. "HACCP Adoption in the U.S. Food Industry." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St Paul, MN: Eagan Press, pp. 15-28.
- Mazzocco, M. 1996. "HACCP as a Business Management Tool." *American Journal of Agricultural Economics* 78(August): 770-74.

- McDowell, R., S. Kaplan, A. Ahl, and T. Roberts. 1995. "Managing Risks from Foodborne Microbial Hazards." In *Tracking Foodborne Pathogens from Farm to Table: Data Needs to Evaluate Control Options*, edited by T. Roberts, H. Jensen, and L. Unnevehr. U. S. Department of Agriculture, Economic Research Service, Miscellaneous Publication Number 1532, Washington, D.C. December, pp. 117-24.
- Narro, C.A., S.A. Malcolm, M. Ollinger, and T. Roberts. 1999. "Pathogen Reduction Options in Slaughterhouses and Methods for Evaluating Their Economic Effectiveness." Selected paper presented at the American Agricultural Economics Association annual meeting, Nashville, TN, August 8-10.
<http://agecon.lib.umn.edu/> (May 4, 2001).
- National Research Council. 1985. *Meat and Poultry Inspection: The Scientific Basis of the Nation's Program*. National Academy of Sciences reports. Washington, D.C.: National Academy Press.
- Nganje, W.E., and M.A. Mazzocco. 2000. "Economic Efficiency Analysis of HACCP in the U.S. Red Meat Industry." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St. Paul, MN: Eagan Press, pp. 241-66.
- Ollinger, M. 2000. "Market Influences on Sanitation and Process Control Deficiencies in Selected U.S. Slaughter Industries." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St. Paul, MN: Eagan Press, pp. 171-85.
- Ollinger, M., and J. Fernandez-Cornejo. 1995. "Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry." U.S. Department of Agriculture, Economic Research Service, AER 719, Washington, D.C., June.
- Onal, H., L.J. Unnevehr, and A. Bekric. 2000. "Regional Shifts in Pork Production: Implications for Regional Competition and Food Safety." *American Journal of Agricultural Economics* 82(4, November): 968-78.
- Osteen, C. 1994. "Pesticide Regulation Issues: Living With the Delaney Clause." *Journal of Agricultural and Applied Economics* 26(1, July): 60-74, 90-96.
- _____. 2001. "What Are the Implications of the Current Assessment of Risks of Organophosphate Pesticides? U.S. Department of Agriculture, Economic Research Service.
www.ers.usda.gov/Briefing/AgChemicals/Questions/pmqa7.htm (April 2001).
- President's Council on Food Safety. 1999. "Egg Safety from Production to Consumption: An Action Plan to Reduce *Salmonella Enteritidis* Illnesses Due to Eggs."
<http://www.foodsafety.gov/%7Efsg/ceggs.html%20> (April 2001).
- Roberts, T., A. Ahl, and R. McDowell. 1995. "Risk Assessment for Foodborne Microbial Hazards." In *Tracking Foodborne Pathogens from Farm to Table: Data Needs to Evaluate Control Options*, edited by T. Roberts, H. Jensen, and L. Unnevehr. U.S. Department of Agriculture, Economic Research Service, Miscellaneous Publication Number 1532. Washington, D.C., December, pp. 95-115.
- Rola, A.C., and P.L. Pingali. 1993. *Pesticides, Rice Productivity, and Farmers' Health: An Economic Assessment*. International Rice Research Institute, Philippines, and World Resources Institute, Washington, D.C.

- Roosen, J., and D.A. Hennessy. 2001. "Capturing Experts' Uncertainty in Welfare Analysis: An Application to Organophosphate Use Regulation in U.S. Apple Production." *American Journal of Agricultural Economics* 83(1, February): 166-82.
- Segerson, K. 1999. "Mandatory Versus Voluntary Approaches to Food Safety." *Agribusiness* 15(1): 53-70.
- Swinton, S.M., and S.A. Batie. 2001. "FQPA: Pouring Out (In?) The Risk Cup." *Choices*. First Quarter, pp. 14-17.
- Teague, M.L., and B.W. Brorsen. 1995. "Pesticide Productivity: What Are the Trends?" *Journal of Agricultural Economics* 27(1, July): 276-82.
- U.S. Department of Agriculture (USDA-FSIS), Food Safety and Inspection Service. 1996. "Pathogen Reduction Hazard Analysis and Critical Control Point (HACCP) Systems: Final Rule." Docket No. 93-016F, *Federal Register* 61, no. 144 (July 25): 38805-38989.
- U.S. Environmental Protection Agency (U.S. EPA). 2000. "Guidelines for Preparing Economic Analysis." EPA 240-R-00-003. September 2000.
<http://www.epa.gov/economics/> (May 4, 2001).
- U.S. Food and Drug Administration (U.S. FDA). 2000. "Food Labeling, Safe Handling Statements, Labeling of Shell Eggs; Refrigeration of Shell Eggs Held for Retail Distribution; Final Rule." *Federal Register* 65 no. 234: 76091-76114.
<http://vm.cfsan.fda.gov/~lrd/fr001205.html> (May 2001).
- _____. 1998. "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables." <http://www.foodsafety.gov/~dms/prodguid.html> (May 2001).
- _____. 2001. "Hazard Analysis and Critical Control Point (HACCP); Procedures for the Safe and Sanitary Processing and Improving of Juice; Final Rule." *Federal Register* 66 no.13: 76091-76114 (January 19, 2001). <http://vm.cfsan.fda.gov/~lrd/fr001205.html> (May 4, 2001),
<http://www.fda.gov/OHRMS/DOCKETS/98fr/011901d.pdf> (May 4, 2001).
- _____. 1995. "Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products: Final Rule." *Federal Register* 60, no. 242 (December 18): 65096-65202.
- Unnevehr, L.J., ed. 2000. *The Economics of HACCP: Costs and Benefits*. St. Paul, MN: Eagan Press.
- Unnevehr, L.J., and H.H. Jensen. 1999. "The Economic Implications of Using HACCP as a Food Safety Regulatory Standard." *Food Policy* 24: 625-35.
- _____. 1996. "HACCP as a Regulatory Innovation to Improve Food Safety in the Meat Industry." *American Journal of Agricultural Economics* 78(August): 764-69.
- Unnevehr, L.J., M.I. Gomez, and P. Garcia. 1998. "The Incidence of Producer Welfare Losses from Food Safety Regulation in the Meat Industry." *Review of Agricultural Economics* 20(1, Spring): 186-201.
- Wang, C., V. Diderrich, J. Kliebenstein, S. Patton, J. Zimmerman, A. Hallam, E. Bush, C. Faulkner, and R. McCord. 2000. "*Toxoplasma gondii* Levels in Swine Operations: Differences Due to Technology Choice and Impact on Costs of Production." Paper presented at the International Association for Agricultural Economics meetings, Berlin, Germany, August.

- Worth, T.W. 2000. "The Cost of an Outbreak in the Fresh Strawberry Market." In *The Economics of HACCP: Costs and Benefits*, edited by L. Unnevehr. St. Paul, MN: Eagan Press, pp. 187-98.
- Zaibet, L., and M. Bredahl. 1997. "Gains from ISO Certification in the UK Meat Sector." *Agribusiness* 13: 375-84.
- Zilberman, D., and K. Millock. 1997. "Pesticide Use and Regulation: Making Economic Sense Out of an Externality and Regulation Nightmare." *Journal of Agricultural and Resource Economics* 22(2, December): 321-32.
- Zilberman, D., A. Schmitz, G. Casterline, E. Lichtenberg, and J.B. Siebert. 1991. "The Economics of Pesticide Use and Regulation." *Science* 25(August): 518-22.