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Food-system risk analysis and HACCP

Helen H. Jensen[*]

Introduction

Controlling food-safety risks has received increased public and private attention in the last several years. The increased attention stems from several sources. New scientific evidence has linked food-borne hazards to human health; consumers now demand higher levels of food safety because of higher income; and consumers have increased preferences for "food-safety attributes" in foods due to greater awareness of food-borne problems. Other changes in food markets and supply contribute to the rise in food-safety problems. The increase in consumers' food spending to away-from-home sources of food has shifted control of food preparation and service away from consumers' control. Recurring food recalls, well-publicized food-borne health risks and threats (including new concerns about bio-terrorism) and large-scale, centralized production and distribution channels have heightened consumers' awareness of the vulnerability of their food supply to food-borne hazards. In addition, as technical and trade barriers to food trade have fallen, trade in food products has increased and imported foods represent a growing source of foods in many countries. This trade also introduces new sources of risk in the food supply through easier transfer of food-borne hazards and plant and animal diseases.

The changes in food markets and increased awareness of food-borne illness as a public-health concern have led to increased public and private demand for food safety. Private certification (both self and third party), related contracting schemes, and quality-control systems have become important methods of quality assurance in food marketing and trade. In the public sector, there has been increased interest in policies and regulation to assure public health and, at the same time, make efficient use of public resources. Significant innovation in both the private and public sector has led to the development of methods and institutions to improve safety of products and assure consumers of the safety of the food supply.

Food-safety assurance is at the heart of the food-safety problem. Private markets often fail to provide adequate food safety because information costs are high, detection often very difficult, and the nature of the contamination is complex. Underlying many of the food-safety failures is the existence of externalities, or costs not borne by those whose actions create them. Externalities tend to arise when strong dependencies govern relationships between economic agents, and when the production environment is not sufficiently well understood to allow market-based solutions (Hennessy, Roosen and Jensen 2002). Strong dependencies between agent decisions exist in food supply chains. Microbial agents are widespread, can lead to significant hazards, are often difficult to detect, and can re-enter the food supply chain, even after control at earlier stages. When firms are not able to capture fully the

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[*] *Department of Economics, Iowa State University, 578 Heady Hall, Ames, IA 50011, USA*

returns from incorporating costly controls of product hazards, they lack the incentive to implement production methods to assure a safer product.

Many governments have taken a new approach to ensure the safety of the food supply that rests on an increased “scientific basis” to food-safety control and risk-assessment framework. This emphasis can be illustrated by control of microbial hazards in products of animal origin, and the focus in this paper is on meats, poultry and animal products. Mandated use of Hazard Analysis of Critical Control Points (HACCP) systems has placed focus on verifiable control in the food production process. In the United States, HACCP was mandated for seafood in 1994 (Procedures for the safe and sanitary processing and importing of fish and fishery products: final rule, docket no. 93N-0195 1995), for meat and poultry in 1996 (Pathogen reduction hazard analysis and critical control point (HACCP) systems: final rule, docket no. 93-016F 1996), and for fresh fruit juice in 2001 (Hazard analysis and critical control point (HACCP): procedures for the safe and sanitary processing and improving of juice: final rule 2001); and regulations taking a risk-based approach have been mandated for shell-egg handling (Food labeling, safe handling statements, labeling of shell eggs; refrigeration of shell eggs held for retail distribution: final rule 2000).

The European Union directive 93/43, effective in December 1995, requires member states to adopt a HACCP approach in obliging food companies to follow HACCP principles in their production process (Grijspaardt-Vink 1995; Ziggers 1999). The companies, themselves, are responsible for monitoring their food safety, although final authority lies with the national authorities (Bunte 1999). The recent European Communities (EC) White Paper on Food Safety (*White paper on food safety* 2000) identifies the guiding principles for food-safety policy to include:

- taking a comprehensive, integrated approach throughout the food chain;
- identifying responsibility for food safety through the food chain – from farm to table;
- basing food-safety policy on the foundation of risk analysis in the design of standards; preventing hazards through the use of HACCP;
- and implementing traceability to assure monitoring as required to protect the safety of materials and inputs.

The growing use of HACCP as a sanitary standard in international trade led the Codex Alimentarius to adopt guidelines for HACCP in 1993, and to incorporate HACCP into food-hygiene codes starting in 1995 (Whitehead and Orriss 1995), cited in (Unnevehr and Jensen 1999)).

Despite the general acceptance of HACCP by regulators and international agencies, there are several issues concerning its mandatory imposition and use as a regulatory tool, especially in light of greater emphasis in taking a comprehensive and integrated approach throughout the food chain. First there is concern about how effectively the use of HACCP will control or eliminate some food-safety hazards when applied in food-safety regulations aimed at the firm (Hathaway 1995). Second is the question of whether the nature of HACCP as a regulatory tool changes when moving from a firm to a farm-to-table approach, when dependencies govern relationships among agents. And third is the question of how cost–benefit analysis can be integrated into farm-to-table risk analysis. This is to allow for evaluation of alternative interventions or systems of prevention and to investigate whether a systems-based approach is likely to lead to lower costs of food-safety control than one based on controls in each stage of the process.

This paper begins with an overview of the types of costs and benefits used in regulatory cost–benefit analysis. The focus is primarily on the approaches that have been used to measure costs. I draw from Unnevehr and Jensen (Unnevehr and Jensen 2001) and summarize what is known from studies of the costs of control of microbial hazards. This is followed by a discussion of the systemic nature of risk in the food system. By exploring the nature of systemic risk in the provision of food it is possible to gain a better understanding of how moving to evaluation of risks in an *integrated* framework can guide alternative food-safety control policies (Hennessy, Roosen and Jensen 2002). The alternative types of risk in the food system are used to motivate consideration of linkages in farm-to-table risk analysis and approaches to control the risks. Two examples illustrate the farm-to-table approach and use of HACCP in control systems. The final section uses the examples and taxonomy of system risk to consider the nature of cost evaluation and implications for costs in systems of control.

Approaches to measuring social costs and benefits

The Environmental Protection Agency (EPA) recently published guidelines for cost–benefit analysis of environmental regulation (*Guidelines for preparing economic analysis* 2000). These provide a useful starting point. As described there, and discussed elsewhere in this proceedings, the valuation of benefits assigns monetary values to the market and non-market benefits of regulation. The social benefits of improved food safety include reductions in risks of morbidity and mortality associated with consuming contaminated food. There are several accepted ways of assigning valuations, including welfare measures of willingness to pay/willingness to accept. In the food-safety area, quantification of the physical effects of the regulation or policy analysis on reduced morbidity or mortality can lead to assignment of values through the use of cost-of-illness methods. These methods estimate the change in explicit market costs associated with reduced incidence of an illness (or death) due to a policy or regulation. The uncertainties in the assignment of benefits may be significant due to lack of data.

The costs that result from regulation include four types of costs: real-resource compliance costs, government regulatory costs, social-welfare losses, and transitional social costs, as shown in Table 1 (*Guidelines for preparing economic analysis* 2000; Unnevehr and Jensen 2001). The costs incurred by firms, which must change production processes in some way to meet new standards or regulations, are termed 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 more difficult to measure, such as changes in labor organization to monitor temperatures. The simplest kind of cost analysis is an accounting for these costs within a static framework (e.g., so many plants pay so much extra per unit of output). Government regulatory costs include the governmental costs to administer, monitor and enforce the food-safety policies. This may include the costs of inspectors, plant monitoring and testing.

The direct costs to firms lead to other changes in markets, such as social-welfare losses from higher consumer prices for meat products or increased costs of litigation, or transitional social costs, such as possible firm closings due to inability to meet standards competitively (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 implications for public policy.

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 – More frequent cleaning – – Training of employees in HACCP procedures – Lower quality of product with reduced pesticide use
Government regulatory costs	– Federal, state or local government costs to administer, monitor and enforce new policies	– Inspectors – Mandated testing – Regulatory reporting costs
Social-welfare losses	– Higher consumer and producer prices leading to changes in consumer and producer surplus	– Higher prices for meat products – Higher insurance costs against recalls
Transitional social costs	– Legal/ administrative costs – Firm closings – Unemployment – Resource shifts to other markets – Transactions costs – Disrupted production	– Regional shifts in production – Small meat-processing plants shut down – Reduced stock value due to recalls

Adapted from Exhibit 8-2, in U.S. EPA “Guidelines for Preparing Economic Analysis” (2000). Based on Unnevehr and Jensen (2001).

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 (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. (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 its resulting costs. Hayes et al. (Hayes et al. 2001) show that, although the effects of a ban on antimicrobial growth promotants in US swine feed would increase costs to producers by US$ 6 per pig head initially; the costs would fall over the 10-year period examined and profits would recover some. This is due to increased output prices with smaller supplies. Such dynamics are important in determining incentives for innovation and compliance.

Findings related to costs of regulating microbial hazards

Microbial hazards are naturally occurring organisms. 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. Unnevehr and Jensen (Unnevehr and Jensen 2001) review recent findings with respect to costs of control and HACCP. This section draws on their review. HACCP systems substitute process control (that includes significant data collection, monitoring and management in the production process) for the costs of testing end product. The HACCP controls are motivated by emphasis on prevention and the use of easily accessible indicators in efforts to reduce food-safety hazards (Unnevehr and Jensen 1996; MacDonald and Crutchfield 1996)

As applied in the US to the seafood, meat/poultry and juice industries; and in the EU to food processors and to the feed industry, specific HACCP plans are not mandated, but are incorporated in a regulatory framework that shifts responsibility for control of hazards to the firm level. Individual firms can develop plans relevant to their particular product mix and plant situation. 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.

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. A number of studies have been undertaken of HACCP (see the collection of studies in (Unnevehr 1999), 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 FSIS and FDA underestimated the costs of HACCP in their *ex ante* analyses. For example, Jensen and Unnevehr (Jensen and Unnevehr 1999) estimate that modifications of pork slaughter processes to reduce pathogens would cost US$ 0.20 to 0.47 per carcass, substantially more than the FSIS estimate of US$ 0.0056 for process modifications (Crutchfield et al. 1997). Antle (Antle 2000) analysed past costs of quality improvement in the meat industry. He extrapolated that a 20% improvement in safety would have additional costs in the range of 1 to 9 US$ cents per pound of product, which is several times larger than the FSIS estimates of less than one one-hundredth of a cent per pound.

Recent studies show that the marginal costs of pathogen reduction are increasing and suggest that complete control is quite costly. Jensen, Unnevehr and Gomez (Jensen, Unnevehr and Gomez 1998) found that pathogen-control marginal-cost curves are steeply increasing in both beef and pork. Costs rise from US$ 0.20 to 1.40 per beef carcass and from 3 to 25 US$ cents per pork carcass as pathogen reduction increases from one log to 4 logs.[i] Narrod et al. (Narrod et al. 1999) find rising costs of *E. coli* control in beef-packing plants – costs rise from 5 to 45 US$ cents per carcass as contamination is eliminated from 30% to 100% 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.

To date, actual costs incurred by meat and poultry firms likely are small relative to total costs and product prices. They may be around 1 to 2% of current processing costs (Jensen and Unnevehr 1999). And, although costs are small on average, they may still be enough to shift the distribution or scale of production at the margin. Small firms' costs are likely to rise proportionally more than large firms' with the implementation of HACCP due to large up-front investments in developing and implementing a HACCP plan. 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.

However, the major 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 (Martin and Anderson 1999) report widespread adoption of HACCP and/or food-safety control procedures among US food-processing firms. Almost 70% 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. Bunte (Bunte 1999) finds that in the Dutch food sector, HACCP tends to be implemented in the more concentrated industries, characterized by economies of scale. If market incentives drive firms to adopt food-safety practices then it is not clear to what extent additional food safety is a result of regulation or how to assign costs to the this component.

The adoption of tighter food-safety controls at one part of the food chain is likely to create incentives that are passed back to suppliers through the marketplace. The experience in Europe indicates 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). In the US, such contracts tend to be motivated entirely by market incentives and there is less reported evidence that regulation has played a role.

The review of costs associated with microbial-hazard control shows inherent flexibility in the adaptation of HACCP control systems to the regulatory use. At the firm level, the evidence shows that the marginal cost of food-safety improvements is likely to be rising. Also, there are both private as well as regulatory incentives for improving food safety at the firm level. The question now is what are the cost implications of taking a farm-to-table systems-based approach to food-safety risks in the food chain?

The food system

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 2001; 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 from 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, Roosen and Jensen 2002). Testing of products 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 care taking, 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 product to intermediaries that co-mingle beef from several sources have market incentives to adopt technologies that reduce pathogens in the plant source.

Figure 1 illustrates the type of systemic risks that can occur due to the interconnectivity of the food system. The figure illustrates the nature of failure in the system in the case when the cause of a failure is known, and when it is not known. Suppose that there are three retailers (or restaurants) that source from two providers. In Figure 1 the three retailer nodes are on the right. Arrows indicate the direction of product flow. Retailer *r1* sources from provider *p1* only, retailer *r3* sources from provider *p2* only, while retailer *r2* sources from both *p1* and *p2*. The circular arrows at the retailer nodes indicate that the retailers also provide some of their own inputs.

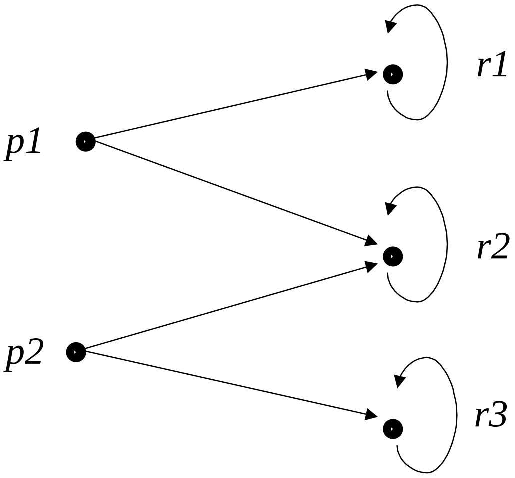

Figure 1. Node diagram of retailers and providers (from Hennessy, Roosen and Jensen2002)

If an illness arises at *r1*, then, without any information on the source of the problem, nodes *r1*, *r2*, and *p1* will have to close for quality audits. In contrast, if problems were detected at node *r2*, then the whole system would have to close down for audit. Node *r2* is the node most strongly connected among all the nodes in the system, and the systemic risk associated with a problem that becomes evident there is most severe. In comparison, if the cause of the problem were known, the system losses might be smaller (and would never be larger). If the problem was observed in *r2,* but also the cause was known to be *r2*, the losses would be limited to this single node.

A variant on this case is when the cause is known but mixing occurs. Figure 2 shows the system where there is contamination in an ingredient used in producing products *b1* and *b2*. If contamination developed in a meat or feed source, it would spread throughout the system even though the cause is known. Products would need to be removed from the system from all sources that received the ingredient due to mixing.

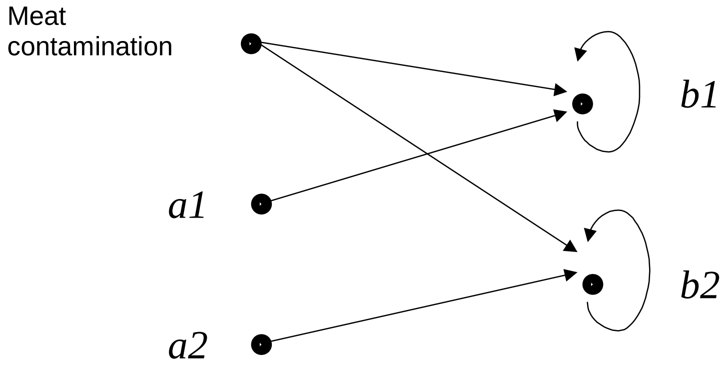

Figure 2. Node diagram of ingredient mixing (adapted from Hennessy, Roosen and Jensen 2002)

Interconnectivity may also give rise to complementarities in input use (care in one area may increase the likelihood of taking care 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. 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., incentive paid by the packer firm for feed 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 interconnectivity in systems stemming from the cases presented in Figures 1 and 2 can be represented by identification of connections and information about the source of contamination problems. Probabilistic Scenario Analysis (PSA) and closely related Fault Tree Analysis (FTA) are tools that have been 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 (see, for example (Roberts, Ahl and McDowell 1995)). The PSA or FTA approach takes account of 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 pathway (most likely) becomes a likely candidate for control analysis.

Today, the system-wide risk-assessment framework is being applied in several studies, including ones on the potential for BSE in the United States (Cohen et al. 2001), the risk of Shiga-toxin-producing *E.coli* O157:H7 in steak tartare (Nauta et al. 2001) and on the risk of occurrence of *E.coli* O157:H7 in ground beef (2001). To illustrate, the USDA *E.coli* O157:H7 study provides a comprehensive evaluation of risk of illness from *E. coli* O157:H7 in US ground beef based on available data and assignment of the risk due to contamination throughout the farm-to-table continuum. The distributions of risk, including information on the variability and uncertainty in the assignment, account for full information on the risks and control measures. The exposure assessment includes production, slaughter and preparation stages. 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 at the production (farm) level and whether the pathogen is detected at entry to the slaughterhouse. The slaughter operation is the second stage in the food chain or processing system. Later stages in the system occur through food preparation (processing and fabrication, distribution and transport, wholesale/retailing and finally at the consumer level with cooking and consumption). In the food production system, each of these stages offers potential for contamination or recontamination.

In principle, information on the probabilities and paths in the production system can be used to assign expected costs to various control options, and 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 models used to evaluate beef processing (Jensen, Unnevehr and Gomez 1998; Narrod et al. 1999) and pork processing (Jensen and Unnevehr 1999) that identify the cost-efficient combinations of interventions. 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). Demands for data to support such analyses are very large. Although the PSA/FTA and farm-to-table risk-assessment approaches describe system linkages in food production, they give limited guidance for identifying strategies to reduce hazards across the whole system. They fail to account for incentives that may lead to different behaviors and choices of technologies and controls among stages.

Two examples

The complexity of most food production today suggests the importance of considering food-safety problems from the systems perspective. Two examples illustrate the potential for farm-to-table risk analysis and related cost analysis. The first is the action plan developed by the US FDA, FSIS and Animal & Plant Health Inspection Service (APHIS) to eliminate *Salmonella enteritidis* (SE) illness due to eggs (*Egg safety from production to consumption: an action plan to reduce salmonella enteritidis illnesses due to eggs* 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 and 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 3, from the President's Council on Food Safety (*Egg safety from production to consumption: an action plan to reduce salmonella enteritidis illnesses due to eggs* 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 on farm-level testing and egg diversion; the second strategy (Strategy II) directs more 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 identifies explicitly 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.

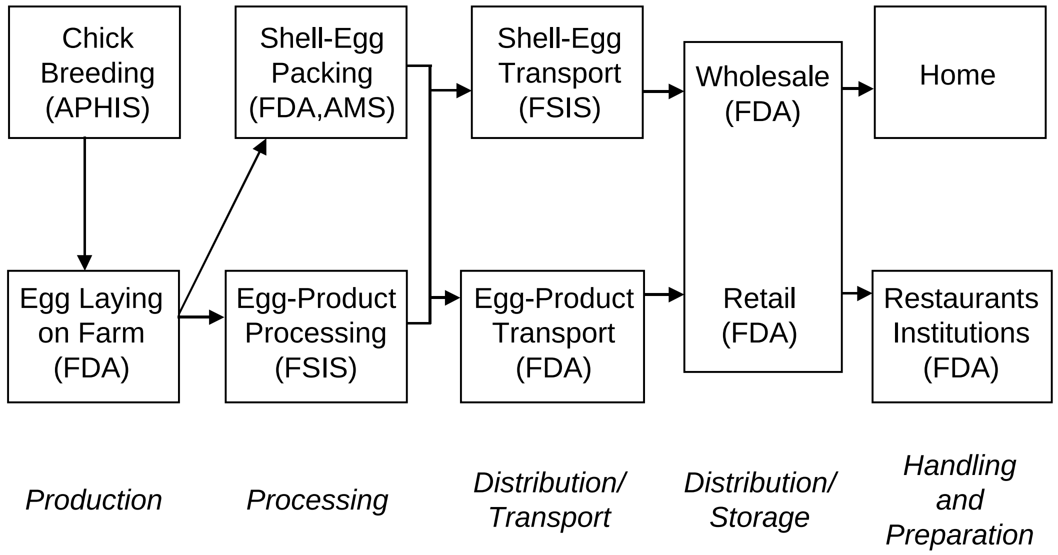

Figure 3. Egg Safety from Production to Consumption

The action plan for SE in eggs provides a good example of how a system-wide approach might be used. In this case, the systems approach facilitated the development and co-ordination 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 to achieve lower costs of controls through market incentives.

The second example is the recent study in Europe of *Salmonella in Pork* (Wong and Hald 2000). The study was a nine-country effort to identify cost-efficient pre- and post-harvest control options based on a multidisciplinary study of the farm-to-table pork production system. Data from the nine countries represent a range of production systems in the EU. Figure 4 shows the pig-meat production chain and the distinction between pre-harvest and post-harvest control. The epidemiological and diagnostic data were collected and evaluated from testing in the participating countries. Control options were identified, as shown in Table 2. Combined collection of data, information from previous studies and expert opinions were used to develop measures of effectiveness of the various control measures. In this assessment, irradiation was the only measure shown to be 100 percent effective.

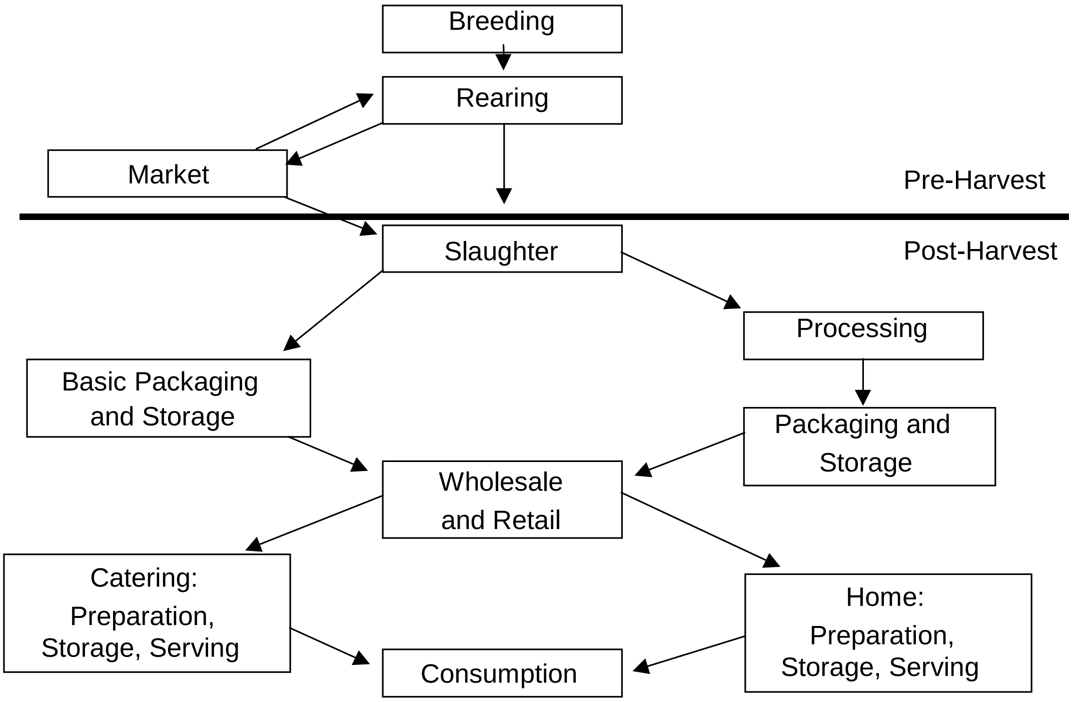

Figure 4. The pig-meat production chain. From Wong and Hald (2000), *Salmonella* in Pork

The results of the epidemiological and diagnostic data and risk assessment were used in the economic assessment of the alternative controls. Costs were developed based on costs assigned to the control measures; benefits were developed based on costs of illness averted, accounting for the control-measure effectiveness. The findings of the economic assessment show that consumer education, on-site food-service training, improved hygiene at slaughter/processing and a chlorine-dioxide wash of pig carcasses were among the controls with highest benefit–cost ratio. All of these measures occurred relatively close to the consumer and retail level. The HACCP controls did not rank among those with highest benefit–cost ratios. However, aspects of the plant-level production process that did rank highly (such as the sanitizing wash) may be related to tighter control of product and treatments at the slaughter/processing level.

Implications for identifying cost-efficient controls in farm-to-table assessments

There are four aspects of a farm-to-table risk, system-wide perspective that have implications for understanding how economics contributes to understanding likely costs of controls and interventions. First, the growing number of studies that take a system-wide, farm-to-table approach have provided good evidence on the weaknesses in data availability and knowledge needed to implement such studies. The significant demand for data and information at each stage is a challenge to each of the efforts and in some cases limits the overall ability to rank the full set of control options. Despite the limitations, the studies reviewed do highlight the contributions of economic information. The distribution of costs is likely to be an important aspect of the effect of controls and regulation in the food system, and likely to be more important than market-price effects.

Table 2. Measures for control of Salmonella in pigs and pig meat

Control Measures	Effectiveness	Benefit to Cost	Rank
1. Regular fumigation of feed mills	80	1.19	12
2. Additional farm cleaning – breeding	40	0.49	15
3. Additional farm cleaning – finishing	40	0.27	16
4. Addition of organic acid to feed	40	2.15	10
5. Addition of organic acid to drinking water	40	7.77	7
6. Construction of pen separations	20	29.48	4
7. Move to all-in/all-out	40	2.79	8
8. Improved hygiene at slaughter/processing	80	31.16	3
9. Mandatory HACCP at slaughter/process	90	2.79	9
10. Chlorine-dioxide wash of pig carcass	50	23.3	5
11. Irradiation of pig meat - all regional	100	1.98	11
12. Irradiation of pig meat - on-site/contract	100	1.08	13
13. Irradiation of pig meat - all on-site	100	0.63	14
14. Additional on-site food-service training	52	46.26	2
15. Additional food service sector training	52	10.65	6
16. Additional consumer education	17	54.44	1

From: Wong and Hald (2000), *Salmonella* in Pork

A second finding is that greater benefits are likely to be achieved and at lower cost to society, with incentive-based measures. Allowing market adjustments to mitigate costs, improving upon existing market incentives, and facilitating private market mechanisms that include contracting of product will be the most effective way to reduce the costs to society of food-borne diseases.

Third, regulation is likely to have an impact on long-run incentives to invest in new technologies or inputs. Not only do technologies related to control of hazards contribute to reducing hazard, but technologies designed to identify the cause of failure will limit the losses in the system associated with failures.

And finally, a risk-based systems approach can be the best way to understand the costs, incentives and risk outcomes resulting from alternative interventions. Because many food-safety problems stem from problems that are systemic in nature, analysis and policy prescriptions should also have a systemic orientation. Economists have addressed problems of systemic risks in other industries (such as banking and finance). However, they have much to learn from scientists and others who study the biological and physical nature of the system linkages. The combined tools will be needed to reduce the food-safety hazards in the food system with most efficient use of available resources.

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[i] One of the difficulties with 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.