Economics of food safety in chains: a review of general principles

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Abstract

The increased demand for safer food has resulted in the development and introduction of new food safety standards and regulations to reach a higher level of food safety. An integrated approach of controlling food safety throughout the entire food chain ('farm to table') has become an important issue in improving the food safety level, but little is known about its economic aspects. This paper reviews important issues in this field, namely the definition of safe food, the nature of food safety hazards, the establishment of acceptable hazard levels, the strategy of food safety improvement and the methods for valuing the improvement. Methods considered are risk-risk analysis, health-health analysis, cost-effectiveness analysis and conventional cost-benefit analysis. Food safety itself is complex and there is no single indicator to measure it. Also, acceptable levels of food safety hazards need further elaboration to clarify the process of food safety improvement for producers. It is furthermore important to gain more insight into cost-effective ways of food safety improvement throughout the entire chain. Valuation of producers' benefits along the chain and their distribution are urgently needed.

Additional keywords: safe food, food safety hazards, cost-benefit analysis

Introduction

In recent years, consumers' confidence in the safety of food has been damaged mainly due to the effect of a number of food-related crises. These crises include the European Commission's ban on British beef in 1996 because of Bovine Spongiform Encephalopathy (BSE), the Belgian contamination of animal feed with dioxins in 1999, the nitrofen contamination of German organic poultry meat and the Belgian contami-

nation of pig feed with medroxyprogestron acetate (MPA), both in 2002. As a consequence, consumers show growing concerns about food safety hazards and the demand for safer food increases. As demonstrated by Nayga *et al.* (2004) for meat and Novoselova *et al.* (2002) for milk, consumers seem to be willing to pay a price premium for 'safer' food.

The increase in demand for safer food has resulted in the development and introduction of new food safety standards and regulations to reach a higher level of food safety. The complex and inter-linked nature of food safety hazards and food production as a whole has been recognized. An integrated approach of controlling food safety throughout the entire food production chain ('farm to table') has become an important issue in attaining a greater food safety level (Anon., 2000). The design and technical aspects of such a chain approach have been widely discussed, but little is known about the economic aspects of improving food safety in the chain. The literature about the costs and benefits of improving food safety focuses mainly on the processing (Jensen *et al.*, 1998; Gould *et al.*, 2000) and the retailer level (Mortlock *et al.*, 2000). Research at other levels is lacking, including the level of the production chain as a whole.

The objective of this paper is to review important issues in the field of food safety, namely the definition of safe food, the nature of food safety hazards and the establishment of acceptable levels for these, the strategy of food safety improvement and methods for valuing food safety improvement. This paper demonstrates applications of these issues within the chain approach. Throughout the paper, examples are given for the dairy chain. In these examples, the chain includes compound feed production and its transport, the dairy farm itself, transport of raw milk, processing, delivery of fluid (pasteurized) milk, and the retailing and catering sectors.

The structure of the paper is as follows. First, the problems and developments are identified that are unique for the understanding of the technical essence of food safety and the strategy for its improvement. Next, the methods are described that might be used for valuing food safety improvements. Then, a brief overview is presented of economic valuation methods of benefits and costs, and of food safety improvement and some empirical applications of these methods in the chain are described. Finally, the major conclusions and future outlook are presented.

Improving food safety along the chain

There are several important aspects when considering the improvement of food safety. A few key issues, such as the definition of safe food, the nature of food safety hazards and the establishment of their acceptable levels, and the strategy of food safety improvement are presented below.

Safe food and food safety hazards

There is no generally accepted definition of 'safe food'. One of the frequently used science-based definitions is that safe food is "food that is wholesome, and that does not exceed an acceptable level of risk associated with pathogenic organisms or chemi-

cal and physical hazards" (Anon., 1998). As the definition indicates, a number of hazards may cause food-borne illnesses. In the widely recognized Hazard Analysis Critical Control Point (HACCP) concept the term hazard refers to "a biological, chemical or physical agent in, or conditions of, food with the potential to cause an adverse health effect" (Anon., 1997a). This concept permits a systematic approach to the identification of hazards and an assessment of the likelihood of their occurrence during the production, distribution and use of a food product, and defines measures for their control.

Specifically, hazards are caused by any of the following (Anon., 1997b):

1. The unacceptable presence of a biological, chemical or physical contaminant in raw materials or in semi-finished or finished products;
2. The unacceptable potential for growth or survival of micro-organisms, or the unacceptable potential for the generation of chemicals in semi-finished or finished products or in a production line environment;
3. The unacceptable contamination or recontamination of semi-finished or finished products with micro-organisms, chemicals or foreign material.

In other words, hazards can be categorized in three main groups: chemical, microbiological and physical.

Among chemical hazards it is important to differentiate between residues such as veterinary medicines, pesticides and growth promoters, and contaminants such as heavy metals, polychlorinated biphenyls (PCBs) and dioxins.

Microbiological hazards refer to micro-organisms such as bacteria, viruses, parasites, protozoa and fungi. They can be either toxigenic, e.g. *Staphylococcus aureus* or *Bacillus cereus*, or infectious, e.g. *Salmonella, Escherichia coli* or *Listeria monocytogenes*. Despite the long list of potential microbiological hazards, a few species and genera (*Clostridium botulium, Clostridium perfringens, Bacillus cereus, Staphylococcus aureus, Salmonella, Shigella* and *Campilobacter*), and the intestinally pathogenic *Escherichia coli* cause the majority of food-poisoning cases. However, each species has many types. For instance, Salmonella bacteria have over 2300 types, many of which may cause different kinds of illness.

Physical hazards relate to various foreign particles not normally found in a product. Examples are metal, pieces of wood and sand. The nature of physical hazards in the food chain is rather different from the nature of other hazards. Besides, compared with chemical or microbiological hazards, physical hazards are less likely to affect large numbers of people. Therefore, physical hazards are not dealt with in this paper.

Acceptable levels of hazards

The key reason of the complexity of defining 'safe food' is that the acceptable (tolerable) levels of food safety hazards are difficult to set.

The Codex Alimentarius Commission have set acceptable levels of chemical substances that are commonly recognized (Anon., 1997a). For residues an Acceptable Daily Intake (ADI) has been established. For pesticides this limit is determined on the basis of the concept of a Maximum Residue Level (MRL), i.e., the maximum concentration of a pesticide residue resulting from the use of the pesticide according to good

agricultural practice. MRLs are expressed in mg substance per kg food. In the case of veterinary medicines, determination of the limits is based directly upon the ADI. In other words, a hypothetical maximum diet has been composed containing product groups consumed daily, and basically the ADI is distributed over these product groups. For environmental contaminants the term Tolerable Daily Intake (TDI) is often used. The ADI or TDI is the daily intake of chemicals to which consumers can be exposed daily without this having adverse effects on their health. This intake is usually expressed in mg single substance per kg body weight (Nasreddine & Parent-Massin, 2002; Renwick *et al.*, 2003). However, in recent years, the validity of acceptable levels set for single substances has been doubted. Although the available studies on interactions between substances do not support this, there are a number of circumstances – e.g. in case of structural analogues of substances – where combined exposure should be taken into account as part of setting acceptable levels of chemical substances. This has been the approach adopted for food additives in the establishment of group ADIs and for some contaminants in the establishment of toxic equivalency factors for combining intakes of structural analogues (Renwick *et al.*, 2003).

As for microbiological hazards the establishment of acceptable levels is rather different. The approaches to food safety criteria that have been developed are based on end product testing and frequently differ among countries (Van Schothorst, 1998). Because of the non-uniform distribution of micro-organisms in the end product and possible recontamination during the production process these approaches do not guarantee total absence of pathogens. At the same time, microbiological inspection of all food is physically and financially impossible (Van Schothorst, 1999). In addition, it is impractical to apply end-product criteria for products that will have been distributed and probably consumed before examinations are completed (Anon., 1986).

A new risk-assessment based concept of 'Appropriate Level Of (consumer) Protection' (ALOP) was introduced by the World Trade Organization / Sanitary and Phytosanitary Agreement in 1994. An example of an ALOP is that the incidence of human listeriosis related to ready-to-eat foods should not exceed 0.25 cases per 100,000 inhabitants per year. However, the Codex Alimentarius Commission has still to elaborate a procedure for translating such a general risk estimate into a specific microbiological criterion that can be used by producers or authorities (Van Schothorst, 2002). The International Commission on Microbial Specifications for Foods (ICMSF) has therefore proposed to use risk assessments for establishing 'Food Safety Objectives' (FSO). An FSO is "a statement of frequency or maximum concentration of a microbiological hazard in a food considered acceptable for consumer protection" (Van Schothorst, 1998). An example of such an FSO could be that the level of *Listeria monocytogenes* in ready-to-eat foods should not exceed 100 colony-forming units per g food at the moment of consumption. An FSO may serve as an equivalent to the acceptable level of a hazard to be attained by control measures integrated into a quality and safety assurance plan that includes the General Principles of Food Hygiene and the HACCP (Anon., 1997a). Some of these control measures are explicitly expressed as performance criteria, process criteria, or end-product criteria, which may be developed and adopted by producers to meet the FSO (Van Schothorst, 1998).

The concept of FSO is in principle applicable to chemical hazards as well, although

for some substances, like dioxin, it is difficult to define an FSO (De Swarte *et al.*, 2002). In contrast to generally acute symptoms of food-borne microbiological illnesses, chemicals usually cause continuous exposure over a lifetime. Moreover, as other factors may play a role in the occurrence of the illness, in many cases there is no unambiguous causal relationship between a particular hazard and human illness (Renwick *et al.*, 2003).

Nature of food safety hazards

Attaining acceptable levels of food safety hazards involves prevention, elimination or reduction of the hazards by means of a set of diverse actions and activities, i.e., a set of control measures (Anon., 1997). The effectiveness and efficiency of the available alternative measures are affected by the distinctive nature of the hazards. There is a considerable difference between chemical and microbiological hazards.

As stated above, chemical hazards are caused by chemical substances. Once present in the product, chemical substances do not multiply, but the product cannot be decontaminated (Swanenburg *et al.*, 2001). So appropriate measures implemented earlier in the chain prevent the presence of a hazard in later stages. For example, careful use of medicines for dairy cows in the farm stage prevents an antibiotic problem in fluid pasteurized milk.

Distinction should be made between residues and contaminants. *Residues* are man-made substances added during the production process. They enter the chain as a result of particular production decisions (Unnevehr & Jensen, 2001). It is possible to avoid or limit the concentration of residues by different means. An example is the fixation of the withdrawal period in the case of antibiotics used for the treatment of cows. On the other hand, *contaminants* enter the chain unintentionally, uncontrolled and usually unnoticed. They may occur during production as a result of the environment or in the course of processing. Measures that could reduce the level of residues are not generally applicable to contaminants (Hopkin, 1997). Dioxin contamination of the pasture due to close location of the dairy farm to an industry can be an illustration of contaminants entering the food chain via the environment. Because of the common problem of environmental pollution it is difficult to exclude many of the contaminants entirely.

In contrast to chemical hazards, microbiological hazards are caused by natural, living organisms. Because of the various origins, e.g. animals, workers, other environmental contamination or cross-contamination, micro-organisms can enter the chain in any stage. It is hard, probably impossible, to eliminate all potential microbiological hazards from the environment. Besides, if micro-organisms are present in a product, they may multiply themselves, for instance in milk on a farm if the temperature during storage is too high. As a result, control of microbiological hazards in a single stage does not ensure their absence in subsequent stages in the chain. This makes the control of microbiological hazards complicated as a set of measures implemented in one stage has consequences for the subsequent stages in the chain (Unnevehr & Jensen, 2001). Contamination and spread should probably be controlled whenever possible. The lower the pathogen 'load' of primary products (inputs), the smaller the

chance that pathogens reach the consumer and lead to food-borne illness via later stages (Van Schothorst, 1999). Separation of milk from cows with mastitis is an example of a necessary measure at farm level in order to avoid possible problems in the end product.

Although food-borne diseases have been studied for more than 100 years, not all factors that influence their occurrence are known (Van Schothorst, 1999). This is also true for the origin of some hazards. For example, *Mycobacterium paratuberculosis* is the known cause of Johne's disease in cattle and may be related to Crohn's disease in humans. If present in milk in high numbers the organism has been shown to survive laboratory pasteurization treatments. If the link between *M. paratuberculosis* and Crohn's disease is confirmed, other control measures need to be developed (Rowe *et al.*, 2000). For many of the hazards known a complete risk assessment has not been made yet. Furthermore, unknown hazards present in the chain as well as 'new' hazards may emerge because of international trade (import and export) or because of changes in primary production, processing and other practices (Van Schothorst, 1999; Swanenburg *et al.*, 2001). As a response, new control measures will be developed and introduced along the chain to provide a counterbalance.

Strategy of improving food safety

The motivation for improving food safety varies, depending on the party interested. Governments enforce higher safety levels for the nation's food supply in terms of reducing the incidence of food-borne illnesses (Buzby *et al.*, 1998). At the same time producers along the chain try to meet the existing acceptable hazard levels and to minimize the probability that their products are identified as the cause of an illness (Ollinger & Ballenger, 2003).

Despite the different backgrounds, all parties are concerned with the way in which a higher level of food safety can be reached in the most economic way. It is important to realize that complete safety is likely to be unrealistic. A zero-risk standard is appropriate for broken glass in canned food, but may or may not be appropriate for microbial pathogens in raw unbranded products (Unnevehr & Jensen, 1996). It is unlikely that in the foreseeable future it will be possible to deliver pathogen-free food. If possible at all, this would mean taking extraordinary measures worldwide and increasing the cost of food beyond levels most people can afford. For this reason, the best strategy is to establish priorities for hazards, foods and consumer groups by means of risk-management programmes based on risk-assessment. Moreover, applying a number of measures along the chain, including HACCP, can control most potential hazards (Van Schothorst, 1999). Such measures will come at a cost. This aspect will require exploring what combination of available alternative measures is most efficient, i.e., finding the combination where an improved food safety level is weighted against the additional cost throughout the entire chain.

Methods for valuing food safety improvement

The characteristics of food safety improvement analysis will obviously differ depending on who the decision-maker is and what his goals are. Aspects included in the analysis with respect to costs and benefits vary depending on whether the decision-maker's goals include social problems or have a more narrow focus.

Several approaches have been developed to determine and compare benefits and costs of health risk reductions by means of different measures (interventions). These might also be useful for valuing food safety improvement. Table 1 presents the methods for comparing costs with benefits. In general, the approaches can be divided into three major groups: (1) risk-risk and health-health analyses, (2) cost-effectiveness analysis, and (3) cost-benefit analysis.

Risk-risk and health-health analyses

The first group of methods compares costs and benefits without monetizing either costs or benefits. Risk-risk and health-health analyses are such techniques (Kuchler & Golan, 1999).

Risk-risk analysis compares the health risks that interventions can reduce (benefits) with the health risks these programmes create (costs). As benefits and costs are usually expressed in different units, risk-risk analysis offers no estimate of net benefits. For instance, in case of chlorinated water the reduced incidence of infectious diseases would be compared with the increased incidence of cancer. This poses trade-

Table 1. Characteristics of methods for comparing costs and benefits of food safety improvement. Adapted from Kuchler & Golan (1999).

Benefits	Costs	
	Counts of health outcomes	Monetized
Count of health outcomes	Group I	Group II
	Risk-risk and health-health analyses	Cost-effectiveness analysis
Monetized	n.a.[1]	Group III
		Conventional cost-benefit analysis (cost-of-illness and willingness-to-pay)

[1] n.a. = not applicable.

off problems for decision-makers. As a result, risk-risk analysis is most useful in cases where only one alternative is offered and where it must be decided to accept this alternative or not.

Health-health analysis compares a count of deaths averted by interventions with a count of deaths resulting from the cost of intervention. In other words, costs are expressed as taxes that reduce individual disposable incomes and constrain each individual's ability to purchase safety, e.g. 'safer' food. These costs lead to greater mortality and morbidity. Then, benefits are defined as the direct benefits of interventions. Because benefits and costs are measured in the same units (lives), net benefits (reduced deaths) can be calculated. However, until relations between income and morbidity are better understood, health-health analysis is only a suitable method for cases where benefits are expressed in numbers of lives saved.

Cost-effectiveness analysis

The second group of methods (Table 1) includes cost-effectiveness techniques that relate monetized costs to the number of physical benefits. The physical benefits are usually the number of averted adverse outcomes, i.e., mortality and morbidity, which are measured in different ways. First – the simplest way – only deaths prevented are evaluated as years of potential life gained (YLGs). YLGs are calculated as the difference between the expected durations of life with and without the intervention, e.g. HACCP implementation. Adding all individuals' YLGs yields a measure of intervention benefit. However, YLGs do not take into account any benefits from a reduced rate of illness. Second – the broader way – called weighted cost-effectiveness, requires a weighting scheme for both reduced morbidity and reduced mortality. The simplest scheme is healthy years of life gained (HYLGs), which weights morbidity and mortality effects equally. HYLGs are expressed as the sum of the years of life gained because of reduced mortality and morbidity, adjusted for disability. But there are obvious problems in using equal weights for adding reductions in mortality and morbidity, because a year lost due to disease is not the equivalent of a full year of life lost. To correct for these problems, morbidity and mortality years are weighted with unequal weights, calculation of which involves many assumptions. For example, one of the assumptions that can be made is a correction for age by means of disability-adjusted life years (DALYs) gained, which basically are age-weighted HYLGs. Quality-adjusted life years (QUALYs) is another measurement similar to HYLGs and DALYs. It adjusts morbid life years over the individual's lifetime by subjective measures of quality, where a fully functional year of life is given a weight of 1 and dysfunctional years are counted as fractions. Utility or quality-of-life status is more explicitly incorporated in this measurement of cost-effectiveness than in the other measurements, which are limited to disability (Belli *et al.*, 2001). For an example of the possible application of DALY to food-safety cost-effectiveness see Evers *et al.* (2003).

In spite of different levels of complexity, all cost-effectiveness techniques assist in ranking the interventions: the one with the lowest 'cost-benefit' ratio is the most cost-effective. Cost-effectiveness serves best when a final decision has been made to prevent an adverse outcome, but when no decision has been made yet about the type

of intervention. However, cost-effectiveness does not permit comparing interventions from different sectors, i.e., with disparate benefits. For example, the benefits from an intervention to decrease the incidence of human listeriosis are not comparable with the benefits from an intervention to decrease the incidence of an animal disease. As costs and benefits are expressed in different units, there is no way to calculate net benefits. The cost-effectiveness approach cannot reveal whether a highly ranked intervention is actually worthwhile (Kuchler & Golan, 1999).

Cost-benefit analysis

The third group of methods to compare costs and benefits (Table 1) assigns a monetary value to both costs and benefits. A money scale allows comparing and ranking interventions from different sectors. Besides, it permits the making of a trade-off between the interventions and other options of spending money (costs) and getting return (benefits). Another advantage is that such an approach provides an opportunity to calculate the net benefits (benefits minus costs) that express the actual efficiency and desirability of interventions themselves. A programme is worthwhile only if the net benefits are positive. However, assigning a monetary value to food safety benefits involves a large increase in complexity. The most difficult problem in benefit evaluation is assigning an (indirect) value to life gained through reduction in mortality and morbidity caused by food-borne illnesses. It is also important to consider all relevant benefits, but to exclude double counting. In the case of costs, the principles embodied in cost evaluation are well understood, but actually measuring them is not simple. The next two sections deal with specific issues related to benefits and costs of food safety improvement (Kuchler & Golan, 1999; Belli *et al.*, 2001).

Monetized valuation of benefits from food safety improvement

Like with other goods associated with reduced risk of death or injury – such as improved nutrition or improved environmental quality – improved food safety is a non-market good (Van Ravenswaay, 1995). The characteristics of an unregulated market for such goods may lead to higher-than-optimal levels of food safety hazards in food, which could ultimately result in higher incidences of food-borne illness and mortality. This means that society should intervene in the market for non-market goods (Buzby *et al.*, 1998). With food safety, insufficient market working is mainly caused by asymmetry in information about food safety between producers and consumers. While producers, to a large extent, have information about their production process and, consequently, about how safe the product is, there is no incentive to share that information with consumers because of the difficulty of charging a premium for the unobservable increase in safety (Buzby *et al.*, 1998; Skees, 1998). At the same time, stores and restaurants often do not like to market 'safer food' because doing so would imply that their other food might be 'unsafe' (Shorgen, 2003). As a result of the non-market characteristics of improved food safety, non-market economic

valuation methods were developed for measuring its benefits. They are presented later in this section.

Conventionally, benefits resulting from food safety improvement are categorized as direct and indirect. Direct benefits are benefits to which a monetary value can be explicitly assigned. Examples are the medical costs and services avoided, such as doctor visits or hospitalization. Indirect benefits are non-monetary. This means a monetary value can be assigned to such benefits only implicitly, e.g., avoided loss of life or sick days (Belli *et al.*, 2001).

Besides the distinction between direct and indirect benefits, it is also important to distinguish between consumer and social benefits. What individuals may be willing to pay as a consumer for higher food safety levels, i.e., consumer benefits, may not be the same as what they might be willing to pay as a citizen in connection with social benefits. Examples of social benefits include reduction of social care costs and protection of vulnerable, poor or uneducated populations (Van Ravenswaay & Hoehn, 1996). When producers implement interventions, social benefits may also arise from a reduction of monitoring costs for the regulatory authority, for instance reduction of costs of testing (Unnevehr & Roberts, 1996).

Methods for benefit valuation

Two main approaches have been suggested to estimate benefits of improved food safety (i.e., non-market good) in monetary terms: (1) cost-of-illness (COI) and (2) willingness-to-pay (WTP) (Table 2).

The COI method values changes in social welfare by assessing medical expenditures and foregone wages associated with food-borne illness. COI-estimates are calculated from the number of annual cases and deaths of food-borne illness and the number of cases that develop secondary complications. The corresponding costs include the direct medical costs of an illness, such as medications, doctor visits, and hospitalization, the indirect costs of lost productivity caused by specific food risk, and other illness-specific costs, such as special education and residential-care costs. The human capital approach (discounting foregone income) or labour market approach (using wage differences between occupations with different risks) are used to infer lost productivity costs that represent the value of saving lives (Buzby *et al.*, 1998; Antle, 1999). Even though the COI method has been modified to incorporate the value of other intangibles, for instance lost leisure time (Van Ravenswaay, 1995), its major limitation still remains. COI does not fully consider the value that individuals may set on feeling healthy, avoiding pain and suffering, or using their free time. Due to this shortcoming, COI is generally believed to underestimate social costs (Kuchler & Golan, 1999).

In contrast to COI, the willingness-to-pay approach, which is preferred by many economists, theoretically represents the full value of food safety improvements based on individual preference (Van Ravenswaay, 1995). The welfare change is measured directly by the maximum that the average person would be willing to pay to reduce risk, or the minimum compensation he would be willing to accept for an increase in risk (Shorgen, 2003). There is a whole series of methods that elicit willingness-to-pay

Table 2. Comparison of cost-of-illness and willingness-to-pay, the two main methods for evaluating the economics of food safety benefits[1].

	Direct/ indirect[2] (D/I)	Stated/ revealed[3] (S/R)	Self selection[4]	Real money[5]	All risks included[6]	Real choice[7]	Geographical restrictions[8]	Costs of method[9]	Number of respondents	Time commitment[10]
			(Y/N)					(L/H)		
Cost-of-illness	I	n.a.[11]	N	Y	N	n.a.	N	H	H	n.a.
Willingness-to-pay										
Contingent valuation	D	S	Y	N	N	N	N	L	H	L
Conjoint analysis	D	S	Y	N	N	N	N	L/H	H	L
Experimental markets	D	S	partly	Y	Y	N	Y	H	L	H
Hedonic pricing[12]	I	R	N	Y	partly	Y	N	L	H	L
Averting expenditure[12]	I	R	partly	Y	partly	Y	N	L	H	L

1 Y/N = yes or no; L/H = low or high.

2 Direct/indirect = changes in people's well-being are measured directly or indirectly.

3 Stated/revealed = method relies on what respondents say about how much they would be willing to pay for reduced risk or about observed market choices of respondents' behaviour.

4 Self selection = chances that a non-representative group of respondents volunteers to participate in the research

5 Real money = respondents spend real money forced to consider their budget constraints.

6 All risks included = respondents actually consume one of the 'risky' products.

7 Real choice = respondents choose actual food products (no hypothetical scenario).

8 Geographical restrictions = necessary geographical restrictions on sample of respondents.

9 Costs of method = total costs of method.

10 Time commitment = amount of time required by a respondent to complete the tasks within a method.

11 n.a. = not applicable.

12 Potential methods not yet supported by scientific publications with empirical results.

for improving food safety (Table 2). These methods are briefly discussed below.

Contingent valuation and conjoint analysis are direct methods that have been increasingly used to measure consumers' WTP for improved food safety. In the contingent valuation methods respondents are given a hypothetical scenario – usually through various kinds of surveys – involving the choice between different risk levels of food contamination. In a conjoint analysis, individuals are asked to rate or rank a number of product profiles consisting of several attributes, including attributes on food safety and price. Unlike contingent valuation, conjoint methods do not ask directly whether a respondent would be willing to pay for a product with particular attributes. For a more thorough review of the application of these methods to food safety see Buzby *et al.* (1995; 1998) and Latouche *et al.* (1998) for contingent valuation and Halbrendt *et al.* (1995) for conjoint analysis. However, regardless of the method used, respondents still know they are valuing a hypothetical scenario. It cannot be guaranteed that respondents take the scenario at face value without mixing food safety with other aspects of their food purchase such as improved environmental quality or animal welfare (Van Ravenswaay & Hoehn, 1996).

The method of experimental auctions – which has been promoted as a tool to improve contingent valuation of non-market goods – uses real money and real goods (Table 2). The individual chooses between conventional products and products with improved safety, giving undivided attention to the valuation process. However, considerable limitations suggest that experimental markets best serve as a complement to other survey methods. For more details, backgrounds and empirical results, reference is made to Fox *et al.* (1996) and Buzby *et al.* (1998).

Potential approaches that are considered to value food safety improvement are hedonic pricing and averting expenditure approaches, which are commonly used indirect methods for valuing illness (in general) (Cropper, 1995; Van Ravenswaay & Hoehn, 1996), although there are no food safety applications yet. Hedonic pricing assumes that the final price of a product reflects the desirability of all its characteristics, and that higher prices paid for 'safer' food on the actual market are used to estimate the WTP for food safety risk reduction. However, there often are several characteristics that are difficult to distinguish. An example is a premium for organic milk products to avert pesticide residues: it is difficult to determine whether food safety was the (only) reason for the premium, or whether there were other reasons, such as environmental concerns. The approach to avert expenditure uses expenditures on actions to avoid exposure to contaminated food – like thorough cooking, proper storage and sanitation – to measure WTP for safer food. However, averting expenditure also requires taking into account consumers' perception of the actual effect of such actions. For this reason, such indirect methods must be used together with the direct methods.

As demonstrated above and in Table 2, each of the valuation techniques for food safety benefits has some limitations. In addition, for all of these techniques incomplete information is another major issue in measuring food safety benefits. Since the contamination is not visible to the naked eye, individuals are unable to observe the level of food-borne risk contamination (Buzby *et al.*, 1998). In some cases, even if they were able to observe, they may not have sufficient information to be able to judge all the consequences of contamination, such as duration, severity and costs of the health

effects. For more details on how to cope with the problem of imperfect information, reference is made to Van Ravenswaaij & Hoehn (1996).

Issues in evaluating benefits along the chain

Besides consumer and social benefits, there are private benefits for producers along supply chains. Examples include a better process design, possible efficiency gains in the organization of the production process, longer product shelf-life, access to new markets, retention of consumers and promoted image, fewer recalls, greater reliability for customers and less outbreaks of food-borne illnesses, i.e., fewer reasons for litigation (Unnevehr & Roberts, 1996; Jensen & Unnevehr, 2000). As demonstrated by Henson & Holt (2000) for the UK dairy industry, most of these benefits are rather obvious to many producers although it is difficult to assign a specific money value to any of them (Jensen & Unnevehr, 2000). Clarification of the marginal private benefits and their distribution are missing in the literature, both at the level of the single chain participant and for the chain as a whole. Estimating such benefit is important in determining incentives for improving food safety (see also Meuwissen *et al.*, 2003).

Monetized valuation of costs of improving food safety

In general, three social cost categories are considered in cost-benefit analysis of food safety improvement: (1) real-resource compliance costs, (2) social welfare losses, and (3) transitional social costs (Unnevehr & Jensen, 2001).

The *real-resource compliance costs* include the direct costs incurred by producers who must improve food safety by various means, e.g. by purchase, operation and maintenance of new equipment, changes in production process or investments in training of employees. The total amount of the real-resource compliance costs determines whether there are indirect social welfare losses and transitional social costs. If the total amount is relatively small, there are no such indirect costs. If the amount of the real-resource compliance costs is large, the markets for the products involved are affected and social welfare losses and transitional social costs should be accounted for.

The *social welfare losses* include changes in consumer and producer surplus from higher consumer prices for 'safer' food, and administrative costs, such as enforcement and monitoring costs for the regulatory agency (as far as they are not included in compliance costs).

Examples of *transitional social costs* are resource shifts to other markets, e.g. regional and international shifts in meat production, and firm closures due to the inability to meet food safety requirements (Antle, 1999; Unnevehr & Jensen, 2001).

Methods for cost valuation

In order to measure compliance costs and their impact on markets, economists use different modelling tools, such as direct compliance costs (cost accounting), partial equilibrium analysis, multi-market models, general equilibrium analysis, variable cost

function, risk analysis models, and linear programming (Unnevehr & Jensen, 2001). The focus here is on the aspects of compliance cost measurement. Up to now three methods have been used to estimate the costs of reaching a higher level of food safety: (1) accounting, (2) economic-engineering approach, and (3) econometric approach (Antle, 1999).

Accounting within a static framework is the simplest type of cost analysis. In this approach extra costs resulting from various improvements are calculated in detail per unit of output (see Crutchfield *et al.*, 1997). The obvious shortcoming of this method is that it is unable to measure the effect of such improvements.

The *economic-engineering approach* combines detailed technical data on food safety interventions, e.g. pathogen reductions of new technologies with data on input costs of such interventions. This method allows the cost efficiency of different interventions or their combinations to be estimated, and can be used to derive a parametric cost function. A study by Jensen & Unnevehr (2000) applies the economic-engineering approach. However, with both methods normally a typical situation is modelled based on data from a number of 'representative' producers, since it is costly to collect data for each producer.

In contrast to the previous two methods, the *econometric approach* usually does not provide detailed information on the production process. Econometric models use a data set that is representative for a particular group of producers and derive an econometrically estimated cost function, thus reflecting actual production choices (Antle, 1999). For an example of a framework for measuring the compliance costs of a food safety regulation, reference is made to Antle (2000) and Ollinger & Mueller (2003).

Although the approaches to measure the costs of improving food safety are rather straightforward compared with benefit valuation, they are not very easy to apply due to several difficulties.

Firstly, there is great uncertainty about the majority of real-resource compliance costs. In order to determine these, two types of costs need to be considered. The first type comprises costs of implementing food safety measures, i.e., *initial costs.* For instance, in case of HACCP implementation such costs include the design of a plan, consultations and training. The second type comprises *recurring operating costs* – i.e., annual inputs to control food safety hazards, including specific interventions – consisting of variable and fixed costs. Variable costs include costs of process control under HACCP, e.g. different quality inputs, operational costs of equipment, other suppliers and sampling and testing. Because of possible assumptions made for cost analysis, such as the number of critical control points and the number of tests, the variable costs vary greatly. Fixed costs include the costs of process modification. Examples are investments in new capital equipment and process reconfiguration. The fixed costs are very uncertain as well, because the extent of necessary modifications to meet the performance requirements is unknown (Jensen *et al.*, 1998).

Secondly, the dynamics of the adjustment process need to be incorporated into the analysis of real-resource compliance costs. In reality, producers will learn more efficient ways to comply with new requirements of food safety improvement over time (Antle, 1999; Unnevehr & Jensen, 2001).

Thirdly, the cost analysis has to cope with a large heterogeneity among producers.

This includes not only differences in the size of production units but also in the array of raw materials and end products, and, therefore, in the mixture of hazards and in the measures to control these hazards (MacDonald & Crutchfield, 1996).

Another difficulty in assessing costs is that various producers involved in the production along the chain are able to affect in some way the food safety of the end product of the whole chain. The approach of controlling food safety throughout the whole chain ('farm to table') has, therefore, become an important issue in order to reach a higher food safety level (Anon., 2000). Many of the new regulations that are aimed at improving food safety and introduced at different levels of the chain require assurance of food safety from suppliers. In the Netherlands, for example, the Quality Assurance scheme for Farm Milk in the Dairy Chain forces dairy farmers to demand their compound feed manufacturers to become certified for Good Manufacturing Practice, which includes HACCP as well. Then, if the whole chain is considered, compliance costs will include costs borne by all chain participants. Analysis of the costs for the chain as a whole will involve additional considerations, which are discussed below.

Issues in evaluating costs along the chain

As mentioned above, improving food safety along the chain involves the control of various hazards by means of different measures. In evaluating the costs of food safety improvement a number of issues playing a role for a single producer also need to be considered for the chain as a whole.

During the production process, measures applied for the control of one hazard may affect or control other hazards as well, but perhaps not to the same extent (Jensen & Unnevehr, 2000). This is true for the control of microbiological hazards, chemical hazards or both. In the farm stage, for instance, manure can be the source of contamination with *Salmonella* or *Escherichia coli*, so that the measures implemented for manure control will influence both microbiological hazards. Averting cows' access to ditch and surface water while grazing prevents possible chemical and microbiological contamination. Therefore, it is difficult to separate the costs of controlling one specific hazard. It is even more complicated to separate such costs for a measure with a larger scope that can be regarded as a package of measures. A relevant example is the measure 'supply of raw milk from *certified* farms' at the dairy processing level, which includes several measures at the farm level to ensure chemical and microbiological safety of the milk.

Some measures are designed to inactivate both spoilage and pathogenic organisms, for instance milk pasteurization. Thus, safety and quality are jointly affected through certain production processes. For this reason, calculation of the costs of such multiple-effect measures is problematic. It is rather difficult to separate the costs of food safety improvement from other goals of the producer, e.g. overall product quality improvement (Jensen *et al.*, 1998).

Food safety measures are often applied in combination with hazard control throughout the production process. Such combinations of measures often result in non-additive hazard reduction. Therefore, cost evaluation of improving food safety would ideally include cost evaluation of combinations of measures not only at different

Table 3. Examples of cost analysis of food safety improvement at different levels along the production chain; control measures considered and methods applied.

Level along production chain	Examples	Control measures considered	Methods applied
Farm	– Dorn & Bachmann (2000) estimated the costs of general prophylaxis of epidemics, milk hygiene, air-conditioning, veterinary services and medicines. Data are based on the analysis of documents and surveys of managers.	Animal-hygienic measures	Accounting
	– Mark *et al.* (1999) indicated costs per pig of on-farm *Salmonella* testing and collecting samples (laboratory costs of analysing the samples are not considered). Data were obtained through a survey.	On-farm *Salmonella* testing	Accounting
Processing	– Jensen *et al.* (1998) provided an analysis of the cost-effectiveness of different microbiological control technologies in beef and pork processing (fixed, variable and total costs per carcass). Data were obtained directly from input suppliers of new technologies.	Interventions (new technologies)	Economic-engineering approach
	– Jensen & Unnevehr (2000) presented an economic framework for choosing optimal sets of interventions, i.e., choosing the most cost-effective set of interventions to meet a set of pathogen standards. Data were obtained directly from input suppliers of new technologies.	Interventions (new technologies)	Economic-engineering approach
	– Ollinger & Mueller (2003) estimated a cost function that evaluates the effect of critically deficient sanitation and process-control practices on meat processing-plant costs, and assesses whether the costs vary with plant output. Data came from the U.S. Department of Agriculture's Food Safety and Inspection Service datasets and the Longitudinal Research Database of the Center for Economic Studies at the Bureau of the Census.	Sanitation and process control practices	Econometric approach
Retailer/caterer	– Mortlock *et al.* (2000) estimated non-recurring start-up costs (planning and implementing) and ongoing weekly costs (running the HACCP-based system) at micro level of the individual business (small retailers and caterers). Data were obtained through a questionnaire followed by face-to-face interviews with business managers.	HACCP[1]-based systems	Accounting
	– Maruyama *et al.* (2000) performed a preliminary cost-benefit analysis of introducing HACCP in the *kaiware* industry and the school lunch system. Data were obtained from the School Lunch Office of the Board of Education.	HACCP principles	Accounting
Production chain	– Lo Fo Wong & Hald (2000) assessed the costs and benefits of measures for the control of *Salmonella*, implemented at different stages in the pork production chain (pre-harvest and post-harvest). Data were obtained directly from chain participants and relevant authorities.	Interventions	Economic-engineering approach
	– Van Der Gaag *et al.* (2004) explored the costs of different scenarios for the control of *Salmonella*, based on epidemiological analysis in the pork production chain (finishing stage, transportation stage, lairage and slaughtering stage). Data are based on the Dutch Quantitative Information Animal Husbandry, literature and interviews.	Interventions	Economic-engineering approach

[1] HACCP = Hazard Analysis Critical Control Point.

points in the process as shown by Jensen & Unnevehr (2000) for pork processing, but also at different points along the entire chain.

Examples known from literature of cost analysis applied at different levels along the chain and for chains as a whole are presented in Table 3. In general, in research about costs of improving food safety more attention is paid to microbiological hazards. With the exception of extensive literature on the cost impact of pesticide regulation in crop production (Buzby & Spreen, 1995; Ollinger & Fernandez-Cornejo, 1998), only a few studies consider impact and costs of growth hormones or antibiotic control in livestock production (Magrath & Tauer, 1986; Hayes *et al.*, 2001). No research has been published on the costs of control of other chemical hazards regarding food safety, e.g. dioxin.

Furthermore, most of these studies focus on one stage of a particular chain, mainly on the later processing and retailer stages. Few studies have been conducted to explore the costs of improving food safety in earlier stages such as feed and farm stages. To assure safety at the farm level, basic questions such as what measures are needed and at what cost, remain unanswered (Unnevehr & Jensen, 1999). Research about the costs of improving food safety along the entire chain level is beginning to emerge (Lo Fo Wong & Hald, 2000; Van Der Gaag *et al.*, 2003).

The food safety measures considered in these studies include only particular components of improving food safety (Table 3). Examples are HACCP implementation (Maruyama *et al.*, 2000), introduction of new technology (Jensen *et al.*, 1998), a testing plan (Mark *et al.*, 1999) or sanitation and process control (Ollinger & Mueller, 2003). Research publications about cost distribution of these components are lacking. Various producers involved in the production along the chain would be interested in defining the optimal combination of elements of improving food safety. For example, rather than testing raw materials as they are delivered, it may be less expensive to ensure that suppliers are reliable.

Table 3 also shows the methods used in research to measure the costs of improving food safety. Measuring costs was initially done by means of cost accounting: estimating the costs of the improvement of food safety. Ollinger & Mueller (2003) have extended accounting cost analysis by examining how sanitation and process control practices affect the total cost of production. They found that sanitation and process control costs increased the costs of processing plants. Jensen & Unnevehr (2000) developed a nonlinear optimization model for choosing the least-cost set of possible measures (interventions) to reach a certain pathogen standard. Results show that higher pathogen reductions can only be reached at increasingly higher costs. Another conclusion is that food safety improvement will be least burdensome if producers can choose a cost-effective combination of measures.

Conclusions and future outlook

This paper provides an overview of the key technical (definition of safe food, nature of food safety hazards and establishing their acceptable levels, strategy of improving food safety) and economic issues (methods to value food safety improvement) in the field of

food safety. In particular, it reviews the state of the art of these issues with respect to the whole production chain. A few final conclusions can be drawn from this review.

– Food safety itself is rather complex. There is no single indicator that can be used to measure the safety of food products.
– For food safety hazards the established acceptable levels are implicit and need further clarification to make the process of food safety improvement understandable for producers.
– Food safety failures often arise from problems caused by the ability of hazards to enter the production chain at many points. Until now, this technical aspect has been the main guide in the development of a chain approach with respect to food safety improvement, since stages in production and inputs are interconnected.
– The potential economic benefits and costs of food safety improvement and the methods for their evaluation are broadly described in the literature. However, valuation of benefits mostly focuses on consumer and social benefits, which represent benefits only at the end of the chain. A quantitative estimate of private producers' benefits is lacking.
– There is a paucity of research on benefits and costs of improving food safety at the chain level: the insight into economic consequences for different stages of the chain and for the entire chain is not complete. The majority of the existing studies about the costs of improving food safety concentrate on some stages of the chain, mostly on the processing and retailer stages. The few studies that are available at the chain level explore the costs of different combinations of control measures in terms of risk reduction. Little information is available to guide producers along the chain in choosing the cost-effective set of control measures to increase a certain food safety level and to minimize the associated costs. Such optimization of food safety measures using the chain approach may help to identify such least-cost points of interventions for different food safety levels.

The potential for food-borne hazards to enter the chain at many points gives rise to another important issue for future research on food safety improvement along the chain. Owing to the characteristic of these hazards, chain participants must share their responsibility for food safety among each other. However, the scope of each participant's responsibility has not been clarified yet. Normative judgements on how the responsibility should be shared along the chain are implicit in many of the discussions about food safety improvement. Among existing components of improving food safety, traceability systems may be considered as a helpful tool to make this situation transparent. Therefore, further research on the efficiency of traceability systems with different levels of detail would also be useful for food safety improvement along the chain. Furthermore, an understanding of how various chain participants share the responsibility may help to expose possible ways of financing the product liability risk throughout the chain.

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