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Economics applied to food safety

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Food Safety Economics combines the fields of food safety and economics to investigate the allocation of scarce resources and decisions made by economic actors in the food supply chain related to food safety management. Food safety economics provides insights into the economic consequences of contaminated food placed on the market, cost-effective control and monitoring of food safety hazards, the attitude of producers and consumers towards these measures, and incentives of farmers and producers to apply these measures. Research in food safety economics is relatively new and scattered. Comprehensive methods that take into account multiple aspects of food safety economics and stakeholders' preferences increase transparency and facilitate the design of effective food safety control and monitoring and related policy making.

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Introduction

Safe food is food that is produced, stored, and prepared in such a way that, upon consumption, consumers are not affected by either acute or chronic adverse effects upon consumption. Unsafe food means food contaminated with a physical, microbiological or chemical hazard which can result into negative effects to animal and human health. Food contamination can also lead to (large) economic losses related to production and trade in case recalls are needed or in case of food safety incidents. It is, therefore, of utmost importance that both the agro-food industry, including farmers, producers and retailers, and (inter) national authorities assure that only safe food is placed on the market.

Economics is a social science aiming at understanding human behaviour in the production, consumption and distribution of scarce goods and services. Food Safety Economics (FSE) is a relatively new research domain in which the fields of food safety and economics are combined. FSE investigates the allocation of scarce resources and the decisions made by economic actors in the food supply chain related to food safety management. FSE thus provides insights into economic aspects of food safety, which include the aspects of costs associated with contaminated food, the attitude of consumers and the agro-food industry towards food safety, incentives of farmers and the agro-food industry to apply control measures, cost-effective prevention and control measures, and cost-effective monitoring programs for food safety.

This paper gives an overview of the FSE topics covered by studies published in the period 2000–2020. Half of the references cited in this article are published from 2017 onwards. Basic economic methods are not always directly applicable to food safety, and in some cases need to be adapted. In FSE there is often a lack of information and/or data available; this paper describes methods that have been used to support informed and transparent decision-making [1].

Economic impact of reduced food safety

The presence of food safety hazards in our food above certain pre-set thresholds can result into high losses for society as well and for the agro-food industry, including farmers, processors, and retailers. The economic impact of foodborne diseases can be calculated from various points of views, for example, from the societal point of view or from the consumer point of view, and depending on these, will include different cost items.

The costs to society

The costs of foodborne diseases to society – the burden of disease – can help support prioritizing between food safety hazards for allocation of the scarce resources to prevention and control. Costs to society include costs related to medical care, productivity loss, quality of life and mortality [2]. The burden of disease is frequently measured in terms of Disability Adjusted Life Years (DALYs) or, although less frequently used, by Quality Adjusted Life Years (QALYs) or cost-of-illness (CoI). DALYs are the sum of years of life lost due to premature mortality and the years lived with disability. One DALY represents one year of healthy life lost. QALYs take into account the quantity and the quality of life generated by interventions such as measures to prevent or reduce the presence of food safety hazards, like improved hygiene, in food products. One QALY represents a year in perfect health [3]. The CoI method estimates the costs of a foodborne disease in a given timeframe. This methods considers direct health costs (e.g. hospitalization, drugs), direct non-health costs (e.g. transport, informal care) and indirect non-health costs (e.g. absence from work) [4]. The CoI method requires a lot of data on medical treatments of patients and, therefore, is not frequently encountered. Furthermore, CoI estimates have been criticized not to include all the losses caused by foodborne illness since they do not include a valuation in monetary units of the pain and suffering of patients [2].

In 2007, the World Health Organization (WHO) established the Foodborne Disease Burden Epidemiology Reference Group (FERG) to estimate the global burden of foodborne diseases – in terms of DALYs – covering acute effects of microbiological hazards as well as acute and chronic effects related to the presence of chemical hazards in food [5]. The underlying goal of this study was to assemble existing data and to promote national research into the burden of disease [6,7]. Till this WHO study, research on the burden of disease focussed on microbiological hazards only; the WHO initiative for the first time also included chemical hazards such as aflatoxins and dioxins in the burden of disease estimates. The WHO estimated that in 2010, globally, 31 food safety hazards, including bacteria, viruses, parasites, helminths and chemical hazards, resulted into 33 million DALYs, of which 18 million DALYs were attributed to diarrheal disease agents [8].

Many follow-up studies are part of, or based on this WHO initiative, such as a recent study performing a Monte Carlo simulation to estimate the global burden of disease of 13 pathogens, including bacteria and parasites, from animal-derived foods [9]. Other disease burden studies focussed on one product and/or one country, for instance, the estimation of the disease burden from foodborne illnesses in Taiwan [10], the estimation of DALYs related to red meat consumption in France [11], foodborne pathogens in Rwanda [12], and *Campylobacter* in Germany [13], as well as the estimation of QALYs for 14 foodborne pathogens in the US [14]. The CoI method was applied to estimate the economic costs per pathogen for meat-related and poultry-related illnesses in the US [15]. Furthermore, an integrated approach combining veterinary and medical epidemiology, risk assessment for the food chain, agricultural and health economics to support decisions on food safety was presented [16]. In this approach epidemiological and economic models were integrated to evaluate how the burden of disease determines the costs in a wider socio-economic perspective, such as how costs spread across economic sectors and society [17].

The costs for the agro-food industry

Food safety management is an integrated part of food quality management at the agro-food industry. The presence of food safety hazards in concentrations above pre-set limits can potentially lead to costs for the agro-food industry, including costs to comply to regulations, costs for tracing back the contamination, product recalls, plant closing and cleaning, product liability, as well as the prolonged effect on the market due to reputation damage [18].

Most studies focused on estimation of the direct costs of food safety incidents, such as the costs for notifying consumers, recalls, and lawsuits due to microbiological food safety incidents in the US [18]. Since data needed to estimate the costs of food safety incidents are frequently lacking, some authors described a hypothetical incident, focusing on the method and modelling the potential economic consequences for different stakeholders along the supply chain [19–21]. These models allow to analyse changes in the economics losses when implementing food safety prevention and control measures, or improved monitoring.

Other studies focused on the indirect costs of food safety incidents, such as the prolonged effect of recalls on current weekly cattle prices [22], the impact of the aflatoxin incident in 2012–2014 on the Serbian dairy market [23], the potential impacts of three food safety outbreaks in the US (the cantaloupe outbreak in 2008, the spinach outbreak in 2006 and the tomato outbreak in 2008) on domestic shipments, imports and prices of the produce industry [24], and the impact of the Bovine Spongiform Encephalopathy (BSE) crisis in the UK in the 1990s on prices at retail, wholesale, and producer level [25]. Furthermore, a retail demand model to estimate the impact of the US Food and Drug Administration's (FDA) announcement warning consumers about *Escherichia coli* in spinach in 2006 in the US was constructed [26].

These costs estimations show the importance of improved food safety for companies [18] or show the costs and benefits of traceability [27]. The costs of food safety incidents can be used to set the budget for prevention measures and decide upon cost-effective options. Cost-effective prevention strategies are further discussed in the next section.

Prevention and control of food safety

Prevention and control measures

Hazard Analysis Critical Control Points (HACCP) programs aim to prevent or limit the presence of food safety hazards in food, and are part of food quality management. Since resources are limited, FSE can give insights into cost-effective prevention and control strategies, using approaches such as cost-benefit, cost-utility, and cost-effectiveness analyses and, in this way, FSE increases transparency of the decision-making process.

In a cost-benefit analysis, the benefits and the costs are expressed in monetary terms so that a net present value or a cost-benefit ratio of a control measure can be estimated. The challenge is how to estimate costs and benefits (e.g. what is the monetary value of pain?) [1]. The direct costs of an outbreak of *Salmonella typhimurium* in an Australian hospital, as well as the costs of various prevention and control measures were estimated in order to find the most cost-effective prevention measure against this pathogen [28]. A cost-benefit analysis can also be a tool in the public decision making process such as when implementing food safety regulations [29]. The benefits from the regulations, such as improved food safety and reduced health burden, are compared with the costs, for example, costs related to improved hygiene or costs to meet the legal requirements. This has been illustrated with the use of HACCP in meat and poultry in the US [30].

The cost-utility method can be used to compare different prevention and control methods: the incremental costs of a measure is compared to the incremental health improvement, measured in QALYs or, in other words, the additional costs needed to generate one extra year of perfect health. This method was used to estimate the cost-effectiveness of prevention and control measures to reduce *Campylobacter* in broiler meat [31]. A cost-effectiveness analysis compares the relative effects and the relative costs of several prevention and control measures for a particular food safety hazard. The measure of the effect is not expressed in monetary terms, therefore, measures can only be compared amongst each other. Several studies used DALYs to estimate the cost-effectiveness of prevention and control measures against aflatoxins. The costs-effectiveness was expressed in terms of DALYs lost, DALYs saved, or the costs of interventions per DALY [32–34]. Other studies used increased income to estimate the effectiveness of prevention and control measures. The cost-effectiveness of several Good Agricultural Practices, reducing the aflatoxin levels and increasing the yield was investigated in this way [35]. Again with the example of mycotoxins, this time deoxynivalenol (DON) in wheat, the costs of several prevention and control measures to reduce DON contamination and the benefits in terms of increased percentage of wheat not contaminated with DON were estimated [36]. Finally, a simulation model was used to evaluate the economic and epidemiologic consequences of different control measures for *Salmonella* spp. in the pork chain [37,38].

Incentives to apply prevention and control measures

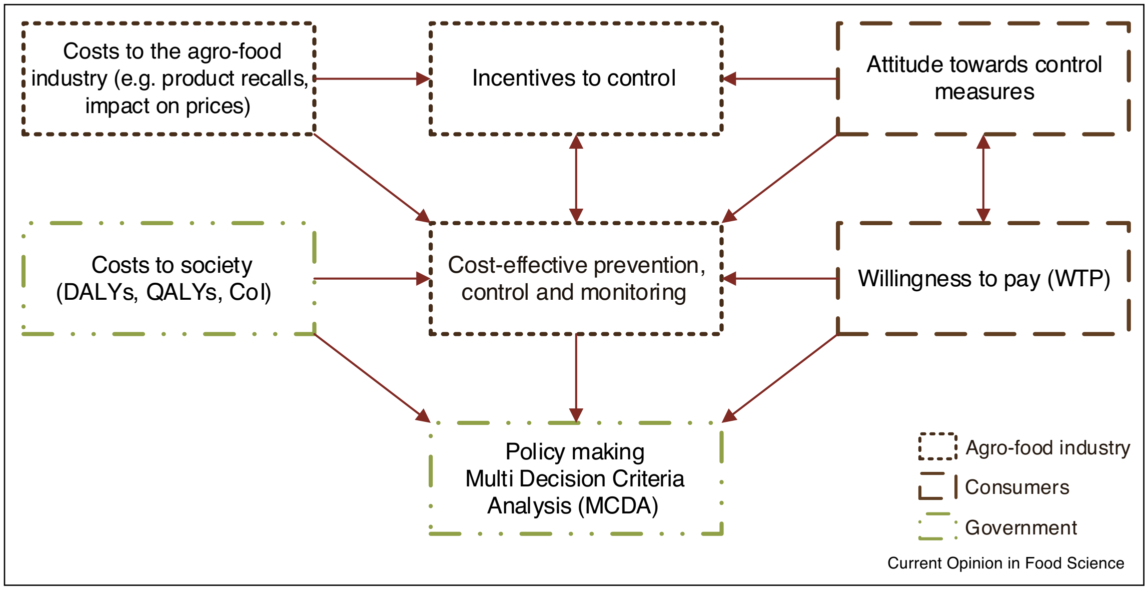
Often, one stakeholder of the food supply chain bears the costs of the prevention and control measures and one or more other stakeholder benefit from these measures. For instance, farmers need to apply prevention measures against *Fusarium* spp. infection in and their related mycotoxins in grains, so to limit the contamination at harvest and the consecutive stages of grain-based feed and food grain supply chains. In this case, incentives to apply prevention measures by actors upstream the chain should be investigated. Economic theory suggests that integrated companies will have fewer food safety incidents because they have more control over the entire supply chain. However, food contamination or even incidents still happen. One cause is information failures [39]. Economic incentives include regulations and public-private partnerships [1]. A change in economic incentive is observed under different contract situations [39].

Primary producers tend to be willing to implement prevention and control measures once well informed about the potential risk and/or consequence of not applying these measures. For example, quite some pig producers in the Netherlands were aware of the sources and consequences of *Toxoplasma gondii* but the knowledge about the public health impact was lacking. Educating farmers was identified as a potential intervention to remove the capability barrier, one of the behavioural factors of pig producers related to control *T. gondii* [40,41]. To control mycotoxins, in corn, cottonseed, and tree-nuts in the US, education across all the relevant industry sectors was identified as a way to improve the adoption of existing mycotoxin control techniques, in addition to providing economic incentives and improving the cost-effectiveness of control methods [42]. Furthermore the pre-harvest control measures against *Fusarium* spp. infection in wheat were identified. Several social-demographic variables such as the level of education were related to the measures applied [43].

Monitoring food safety hazards

Cost-effective monitoring strategies for food safety hazards have been investigated in a few, scattered studies. Each study investigated cost-effective strategies for one specific hazard in a specific food product. Most studies used optimization models solved with linear programming, and focused on investigating cost-effective monitoring strategies at one control point along the food supply chain. The number of samples to collect, the number of aliquots to analyse, and the detection method to use were optimized for mycotoxins in a batch of cereals grains [44]. The number of samples to collect and the pooling rate were optimized for dioxins at bulk milk collection [45]. The number of samples, the sampling interval, and the control limits were optimized for diet components of dairy cow feed [46]. Results of the above mentioned studies are specific to the hazard, product and control points under investigation, and cannot easily be generalized. Some other studies optimized monitoring strategies based on costs and effectiveness along the entire food supply chain. The control points and number of samples to collect at each control point were optimized along the maize supply chain to control for aflatoxins [47] and along the pork production chain to control for dioxins [48].

Figure 1



Relationship between the various aspects of the Food Safety Economics domain.

Stochastic simulation were used to assess the consequences of changing the current monitoring program (replacing the detection method, replacing the matrix, using indicators to identify high risk herd) for antimicrobial residues in Danish finishing pigs [49]. Another application was to evaluate the sensitivity, specificity and monetary benefits – the net economic effect – of a risk-based meat inspection system for bovine cysticercosis, compared to the current system [50]. Results, again, depend on the type of hazard, and the product considered in the particular study.

Consumer attitude towards food safety

In Europe, food safety is considered a prerequisite. The European General Food law states that all food placed on the market has to be safe. Furthermore, food safety is not an attribute that can be observed or tasted like food quality attributes such as texture and colour. Furthermore, food safety is often a post-experience good; only after consumption it is known whether or not the product consumed was safe. This leads to information asymmetry: consumers are often unaware of possible food safety risks. Therefore, it is not straightforward that consumers are willing to pay for food additional safety attributes.

The consumer's willingness to pay (WTP) for food safety attributes has been investigated in several countries for several products. A few recent examples are Fuji apples and shrimp in China [51,52], salmonellosis in Hungary [53], and listeriosis in South Africa [54]. These studies concluded that consumers are willing to pay for food safety, the amount depending on socio-demographic variables such as the education level, and depending on the information received about the food safety risk as well as the implemented control measure [51–55]. Most consumers are willing to receive information, especially the higher educated consumers [56]. The same trend is observed for both primary producer and consumers: they are willing to pay for food safety once well informed about the risks and the control measures.

Towards an integrated approach

To date, the available literature in the domain of FSE, mostly focused on the burden of disease. The remaining economic aspects within the FSE domain – the financial impact of food safety incidents, cost-effective prevention, control and monitoring, the incentives of farmers and the agro-food industry to apply control measures, and the attitude of consumers towards food safety and control measures – are investigated in only a few studies, mostly focusing on one particular pathogen (e.g. *Salmonella* spp. or *Campylobacter*) or chemical (e.g. mycotoxins or dioxins) in a particular product, in a particular region or supply chain. There are very few studies considering multiple food safety hazards or considering multiple aspects of food safety economics. Overall, data and results are scattered over the FSE domain.

Figure 1 summarizes the topics presented in this paper, and their relationships. The aim of providing safe food can be achieved through the combination of prevention, control and monitoring. The factors that influence the allocation of the scarce resources to effectively prevent, control, and monitor food are the costs to society, expressed in DALYs, QALYs or CoI; the costs to the agro-food industry such as implementation costs and product recalls; the attitude of consumers towards control measures, and the consumer's willingness to pay for safe food.

Three main stakeholders are identified: the agro-food industry, including the farmers, the processors, and retailers, the consumers and the government. The agro-food industry initially bears the costs of prevention, control and monitoring measures, and product recalls. Consumers suffer from years of life lost or years of life lived with a disability, and from increased food prices and taxes. Finally, the government bears costs of, amongst others, regulatory enforcement, official control, disease surveillance, crisis management, and indirectly suffers also from years of life lost and lived with disability due to reduced productivity and increased medical costs. Resources spent on food safety are resources that cannot be spent for other aims such as education or public services. Governments have the responsibility of protecting public health and the agro-food industry is responsible for providing safe food. Since the economic impact of foodborne illnesses can be extremely high, private and public sectors need to collaborate and share information [57]. However, each stakeholder has different preferences when it comes to food safety, and consumers might have a different preference about certain control measures than the agro-food industry has.

To facilitate transparent policy making and discussion amongst stakeholders, taking into account these different preferences and viewpoints, a Multi-Criteria Decision Analysis (MCDA) can be performed. MCDA is able to include (a) economic aspects such as burden of disease, the impact on the market, and the costs related to prevention and control, (b) technical aspects such as the ease of using/implementing a control measure, and (c) social aspects such as the attitude of consumers towards control measures. The different criteria can be weighted to have a representation of the common ground existing between the different stakeholders in terms of their preferences for the different policy alternatives [58,59]. MCDA increases transparency in designing effective prevention, control and monitoring programs to guarantee food safety, and related policy making.

Conflict of interest statement

Nothing declared.

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