The Overall Benefits of Food Safety – A Literature Review

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Client Report prepared for the New Zealand Food Safety Science and Research Centre

December 2022

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DRAFT

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Chapter 1
Introduction

The maintenance of safe food supply is important. Food contamination can result in negative impacts on human and animal health, including mortality, illness, disability, and decreased quality of life. It can also lead to significant societal and economic losses related to production and trade in the case of food recalls. Systems for the detection of pathogens, harmful chemicals, and physical contamination in relation to food products are an important tool for maintaining a safe food supply and preventing foodborne illness outbreaks. Science for food safety therefore plays a critical role in protecting the general public and economy from damages related to unsafe food.

New Zealand operates and maintains an all-encompassing and globally recognised food safety system. The relevant legislation has been developed based on guidelines from the Codex Alimentarius Commission and Overseas Market Access Requirements (OMARs). In addition, many domestic food producers and exporters have adopted international food safety programmes recognised by the Global Food Safety Initiative (GFSI), such as Food Safety System Certification (FSSC) 22000, GlobalGAP, and BRC Global Standards (IFC, 2021).

Also, scientific initiatives have been established. In 2016, the New Zealand Food Safety Science and Research Centre (NZFSSRC) was established at Massey University in Palmerston North. The Centre joins with eight science research partners to form a virtual research centre network. It synthesises input from industry, government, researchers and Māori to promote, coordinate and deliver food safety science and research for New Zealand. NZFSSRC is funded by both the government and industry. The Centre's role in underpinning New Zealand's reputation for safe food is vitally important (IFC, 2021).

The aim of this study is to review current literature on the benefits of food safety and the cost of food safety incidents. This also reviews the role, importance and value that science has in order to maintaining food safety and mitigating foodborne hazards and related impacts. The review draws on New Zealand and overseas cases.

The report is structured as follows. After an introduction and an outline of the Global Food Safety Strategy in Chapter 1, the costs to society, industry and the economy as a whole are described in Chapter 2. This is followed by an outline of the value and importance of food safety science in Chapter 3. The report finishes with a conclusion in Chapter 4.

1.1 Global food safety strategy

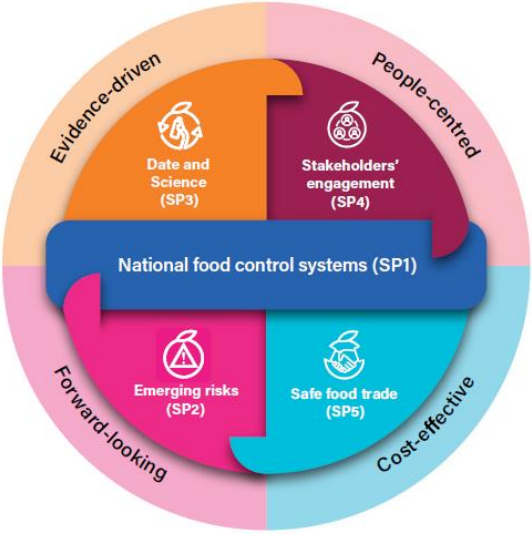
Human consumption of unsafe food containing harmful levels of bacteria, viruses, parasites, chemicals, or physical substances can cause illness, including acute and chronic illness, resulting from more than 200 diseases, ranging from diarrhoea to cancers to permanent disability or mortality. An estimated 600 million people (almost one in 10 people globally) fall ill after eating contaminated food, resulting in a global annual burden of approximately 33 million disability-adjusted life years (DALYs) and 420,000 premature deaths (WHO, 2022a). Low- and middle-income countries (LMICs) are disproportionately affected relative to high-income countries, with an annual estimated cost of US$110 billion in productivity losses, trade-related losses and medical treatment costs due to the consumption of unsafe food (Hoffman et al., 2019; WHO, 2022a).

The globalisation of the food supply means that populations worldwide are increasingly exposed to new and emerging food risks. Global agri-food value chains have become more complex, and food products are often grown, processed and consumed in different countries. While these trends have increased the quantity and diversity of foods available to consumers worldwide, food safety risks have also increased and spread with the large volumes of food traded. The development of international food safety standards has become more critical than ever before. Without prevention-oriented food safety risk management systems, failure to ensure compliance with regulations and standards can lead to societal and economic losses.

Major international agencies, including the Food and Agriculture Organization of the United Nation (FAO) and World Health Organisation (WHO) have listed food safety as a major policy goal. This includes the prevention of food safety incidents (e.g. foodborne illness), and the maintenance and enhancement of safe food supply. These two agencies are also responsible for managing the requirements within Codex Alimentarius (also referred to as Codex). The Codex outlines international food standards, guidelines and codes of practice designed to protect food safety and quality and promote fairness in global food chains. Its standards are adhered to by 189 member states, including New Zealand (FAO/WHO, 2022).

The WHO has developed the Global Strategy for Food Safety 2022-2030 (GSFS). This strategy provides an overall vision and strategic priorities for coordinated global action for food safety. Food safety is also an integral part of the United Nations Sustainable Development Goals (SDGs), factoring into several SDGs. In particular, the WHO (2022b) considers food safety science to be one of five key pillars underpinning the GSFS (see Figure 1-1). This designates food safety science as Strategic Priority 3: Evidence-Driven - Data and Science, alongside the central roles of National Food Control Systems (Strategic Priority 1), identifying Emerging Risks (Strategic Priority 2), Stakeholder Engagement (Strategic Priority 4), and Safe Food Trade (Strategic Priority 5).

Figure 1-1: Conceptual Framework for Strategic Priorities of the WHO Global Strategy for food safety 2022-2030.



Source: WHO, (2022b).

Specifically, Strategic Priority 3: Evidence Driven is broken down into four Strategic Objectives:

Strategic Objective 3.1:	Promote the generation and use of scientific evidence and risk assessment when establishing and reviewing food control measures.
Strategic Objective 3.2:	Gather comprehensive information along and beyond food chain and utilize these data when making informed risk management decisions.
Strategic Objective 3.3:	Source food safety information and risk analysis experiences from beyond national borders to strengthen risk management decisions and technical capacity.
Strategic Objective 3.4:	Consistent and transparent risk management decisions when establishing food control measures.

Under Strategic Objective 3.1, the following recommendations are made:

- *Many Member States need to invest in capacity-building for risk assessment, promote evidence-based health policy-making and strengthen participation in national and regional networks for risk assessment* (WHO, 2022b, p.34).
- *There is also a need for investment in surveillance and monitoring programmes for chemical and biological contaminants in the food chain and developing food consumption databases to generate data for underpinning evidence-based decision-making* (WHO, 2022b, p.34).

Strategic Objective 3.1 also contains a provision that *"applying a risk management framework to establish and monitor food control measures consists of the following well-established steps: …ii. gathering scientific evidence and carrying out an assessment of any risks to consumers…"* (WHO, 2022b). The inclusion of science in international food safety strategic plans shows its critical importance to the prevention of incidents and maintenance of a safe food supply.

Chapter 2

Costs of Food Safety Outbreaks

Food safety incidents with the potential to impact human health and economic systems generate a range of costs. This includes social costs such as mortality, illness and reduced quality of life, public and private costs for treatment and care, as well as productivity loss. Food safety outbreaks can also generate economic costs for actors along the food supply chain, including (but not limited to) producers, processors, retailers, distributors, exporters and consumers, as well as to society and the economy as a whole. These costs can include the cost of incident response, lost revenue and additional costs to food firms, as well as reputational damage and prolonged market effects.

This chapter examines the various costs incurred by food safety incidents, including social and economic costs. While the costs of food safety incidents can be extremely broad and numerous, many studies have focused on those costs that can be effectively measured. Studies across a wide range of food safety incidents globally are included in this review. However, care should be taken when considering studies from overseas for estimating the potential costs of food safety outbreaks in New Zealand. Costs from outbreaks in other countries can vary significantly from those in New Zealand. For example, some countries may use different technology for investigations and/ or may employ different responses to food safety outbreaks. Also, costs for food safety incidents and foodborne illnesses have increased considerably over the last decade, therefore costs from older studies are likely to be underestimates.

2.1 Total costs of food safety

2.1.1 Overview of potential food safety costs

The FAO (2017) have outlined a range of potential costs of food safety incidents, as shown in Table 2-1. These are organised under five categories (1) public health impacts, (2) economic losses, (3) food security, (4) consumer perceptions, and (5) socio-cultural concerns.

Table 2-1: Potential costs of food safety incidents.

Category	Examples of Costs/Harm
(1) **Public health impacts** caused by foodborne hazards	• Immediate illness • Chronic health impairment • Mortality
(2) **Economic losses** related to food products being removed from domestic or export markets due to food safety concerns	• Reduced access to, or share of, domestic and export markets due to hazards in food • Lower market value and/or lower volumes traded or sold due to food safety concerns • Reduced employment and livelihood – potential impact(s) on producers, processors and/or distributers • Loss of community livelihood • Negative impact on non-food sectors (e.g. tourism)
(3) **Food security**, including concerns about utilisation, food access and food availability	• Malnutrition, wasting or growth stunting • Increase in prices due to shortages caused by removal of unsafe foods from the market • Reduced household income due to lower value or inability to sell food products • Decrease in availability due to condemned products or reduced supply • Decrease in dietary diversity
(4) **Consumer perceptions** and acceptance of food safety risks	• Avoid nutritious food choices based on risk perceptions • Lower level of trust in government's ability to ensure safe food
(5) **Socio-cultural concerns** related to protecting vulnerable groups	• Differential impacts on vulnerable sub-groups of the population or on one gender • Isolation and vulnerability increased due to social stigma associated with outcomes from foodborne illness (e.g. epilepsy linked to neurocystiercosis)

Source: Adapted from FAO, (2017).

Also, Buzby and Roberts (2009) outlined an extensive list of potential costs of foodborne illnesses, as shown in Table 2-2. The authors stated "*Analyses that estimate the costs of foodborne disease often include only the medical costs of individuals or household, costs of lost productivity, and premature death and exclude other costs (e.g. pain and suffering, institutional care) because of lack of adequate data*" (Buzby and Roberts, 2009, p. 1852). This suggests that the actual costs of foodborne illness may be far greater than estimates provided by the literature.

Table 2-2: Possible societal costs of foodborne illnesses.

- **COSTS TO INDIVIDUALS OR HOUSEHOLDS**
  - **Human illness costs**
    - Medical costs
      - Physician visits
      - Laboratory costs
      - Hospitalisation or nursing home
      - Drugs and other medications
      - Ambulance or other travel costs
    - Income or productivity loss for:
      - Ill person or person dying
      - Caregiver for ill person
    - Other illness costs
      - Travel costs to visit ill person
      - Home modifications
      - Vocational/physical rehabilitation
      - Childcare costs
      - Special educational programmes
      - Institutional care
      - Lost leisure time
    - Psychological costs
      - Pain and other psychological suffering
      - Risk aversion
  - **Averting cost behaviours**
    - Extra cleaning or cooking time costs
    - Extra cost of refrigerator, freezer, etc
    - Flavour changes from traditional recipes (especially meat, milk, egg dishes)
    - Increased food cost when more expensive but safer foods are purchased
  - **Altruism (willingness to pay for others to avoid illness)**
- **INDUSTRY COSTS**
  - **Costs of animal production**
    - Morbidity and mortality of animals on farms
    - Reduced growth rate or feed efficiency and increased time to market
    - Costs of disposal of contaminated animals on farm and at slaughterhouse
    - Increased trimming or reworking at slaughterhouse and processing plant
    - Illness among workers because of handling contaminated animals or products
    - Increased meat product spoilage because of pathogen contamination
  - **Control costs for pathogens at all links in the food chain**
    - New farm practices (age-segregated housing, sterilized feed, etc)
    - Altered animal transport and marketing patterns (animal identification, feeding or watering)
    - New slaughterhouse procedures (hide wash, knife sterilisations, carcass sterilising)
    - New processing procedures (pathogen tests, contract purchasing requirements)
    - Altered product transport (increased use of time or temperature indicators)
    - New wholesale or retail practices (pathogen tests, employee training, procedures)
    - Risk assessment modelling by industry for all links in the food chain
    - Price incentives for pathogen-reduced product at each link in the food chain
- **OUTBREAK COSTS**
  - **Herd slaughter or product recall**
  - **Plant closings and clean-up**
  - **Regulatory fines**
  - **Product liability suits from consumers and other firms**
  - **Reduced product demand because of outbreak:**
    - Generic animal product, all firms affected
    - Reduction for specific firm at wholesale or retail level
  - **Increased advertising or consumer assurances after outbreak**
- **REGULATORY AND PUBLIC HEALTH SECTOR COSTS FOR FOODBORNE PATHOGENS**
  - **Disease surveillance costs to:**
    - Monitor incidence or severity of human disease by foodborne pathogens
    - Develop integrated database from farm to table for foodborne pathogens
  - **Research to:**
    - Identify new foodborne pathogens for acute and chronic human illnesses
    - Establish high-risk products and production and consumption practices
    - Identify which consumers are at high risk for which pathogens
    - Develop cheaper and faster pathogen tests
    - Risk assessment modelling for all links in the food chain
  - **Outbreak costs**
    - Costs of investigating outbreak
    - Testing to contain an outbreak (e.g. serum testing and administering immunoglobin in the case of hepatitis A)
    - Costs of clean-up
  - **Legal suits to enforce regulations that may have been violated**
  - **Other considerations**
    - Distributional effects in different regions, industries, etc
    - Equity considerations, such as special concern for children

Source: Adapted from Buzby and Roberts, (2009).

Foodborne illnesses have been found to have varying degrees of frequency in different food products. Some sources of foodborne illness (both in terms of product and process) are more common than others. Soon et al. (2020) conducted a review of global food safety incidents determining the factors contributing to food safety incidents internationally. Their review attempted to quantify the most frequent food and beverage categories involved in food safety incidents and product recalls, the most common types of food safety hazards (including allergens, biological, physical, chemical, and other hazards), and known or suspected causes of food safety incidents. The authors found the most common food and beverage categories involved in food safety incidents and recalls to be: raw fish (1,411 incidents); ready-to-eat meals (1,293 incidents); fruits, vegetables and nuts (1,150 incidents); and raw prepared products (999 incidents). Among these, the most common food safety hazards were: allergens (1,354 incidents/recalls); biological hazards (1,176 incidents/recalls); physical hazards (273 incidents/recalls); chemicals (66 incidents/recalls) and other hazards (63 incidents/recalls). Of the allergens, the authors found the most commonly implicated food and beverage products to be: milk (330 incidents/recalls); multiple (324 incidents/recalls); wheat/gluten (135 incidents/recalls) and eggs (128 incidents/recalls). Of the biological hazards, the authors found the most commonly cited pathogens to be: listeria monocytogenes (387 incidents/recalls); salmonella (351 incidents/recalls); and E. coli (210 incidents/recalls). Furthermore, the most common known or suspected cause(s) of food safety incidents were shown to be: undeclared allergens (1,186 incidents/recalls); cross-contamination (838 incidents/recalls); good manufacturing practice failures (269 incidents/recalls); and incoming material control (224 incidents/recalls) (Soon et al., 2020).

2.1.2 Methods for measuring the costs of food safety incidents

Multiple methods for measuring the costs of food safety incidents across a range of impact categories have been suggested in the literature. These include monetary methods, such as Cost-Of-Illness (COI) and Willingness-To-Pay (WTP), and non-monetary methods, such as Disability-Adjusted Life Years (DALYs) or Quality-Adjusted Life Years (QALYs) (Buzby and Roberts, 2009; Focker and Fels-Klerx, 2020).

The first method, Cost-Of-Illness (COI), is an accountancy-type approach that attempts to calculate the total cost of illness in monetary values within a particular time period by summing known costs associated with an illness or outbreak. This method includes direct medical costs (e.g. physician and hospital services), direct non-medical costs (e.g. transportation to healthcare) and indirect costs (e.g. lost productivity). As this method uses exclusively "real" costs (i.e. actual costs incurred as a result of illness), it represents the real costs of illness to society, and provides easily comparable figures across different pathogens. However, this approach has been widely criticised for being too heavily influenced by demographic characteristics (e.g. income, education) and thereby not providing good measures of illness severity, as well as not taking into account aspects such as patient quality of life (e.g. pain) as a result of illness (Buzby and Roberts, 2009; Focker and Fels-Klerx, 2020).

The second method, Willingness-To-Pay (WTP), is an economic valuation method used to determine a consumer's willingness to pay a premium for a specific product, attribute or similar aspect. In the case of food safety cost estimation, WTP is used to estimate consumers' willingness to pay a premium to avoid or reduce the probability of avoiding illness. This approach is capable of taking factors such as pain and suffering and lost leisure time into account but has been less frequently used in the food safety-specific literature (Buzby and Roberts, 2009; Focker and Fels-Klerx, 2020). However, many studies have estimated the value of food safety to food consumers. These are described in detail in Appendix A.

The third method, Disability-Adjusted Life Years (DALYs), is a non-monetary approach used to estimate the number of years of life of those affected by food safety incidents due to premature death or living with disability. One DALY effectively represents one healthy year of life lost due to either mortality or disability, making time the comparable factor across multiple studies. Similarly, the fourth method, Quality-Adjusted Life Years (QALYs), is an adaptation of the DALY approach to include both the quantity and quality of life of those affected by food safety incidents, with one QALY representing one year of perfect health (Buzby and Roberts, 2009; Focker and Fels-Klerx, 2020). Other measures have been used in the literature, such as value of lives lost (VLL) and value of a statistical life (VSL), but these are much less common than those discussed above (EMCDDA, 2017; Scharff et al., 2009; Scharff, 2012).

The FAO (2017) have also suggested a range of criteria and metrics for measuring the relative costs of food safety incidents across multiple categories (including some from Table 2-2). These are shown in Table 2-3. These methods combine scale-based (e.g. binary or Likert) and monetary metrics for measuring the impacts of aspects of food safety incidents, including COI and DALY type approaches.

Table 2-3: Suggested measurements for the relative costs of food safety incidents.

Category	Criteria	Scale
Public health impacts caused by foodborne hazards	Qualitative level of risk	• Binary – “acceptable” or “unacceptable” • Multiple categories – “low”, “medium” and “high”
	Burden of disease 1. Disability Adjusted Life Years (DALYs) 2. Cost of illness	1. Years 2. Monetary scale
Economic losses related to food products being removed from domestic or export markets due to food safety concerns	• Value of exports • Value of domestic market	• Monetary scale • Monetary scale
Consumer perceptions and acceptance of food safety risks	Aggregate measure based on 5 sub-criteria that access consumer perceptions and acceptance (e.g. Ruzante et al., 2010).	Normalized scale between 0 (=low risk/high acceptance) and 1 (=high risk/low acceptance)
Implementation – acceptability of a risk management option in terms of food security	Potential harm to food availability if risk management option is implemented.	Point scale (1 = severe impact on food availability, 5 = no impact)
Implementation - costs	• Initial, one-time cost to implement risk management intervention. • Ongoing operating costs	Monetary scale

Source: Adapted from FAO, (2017).

Some foodborne illnesses may bear greater costs than others. This may be due to differences in the severity of illness and treatment/ care costs. For example, Minor et al. (2015) estimated the relative annual monetary loss of a range of foodborne illnesses in the United States (US), showing a significant variation in annual loss of US$208 up to US$7,013,777 depending on the pathogen involved. Similarly, Sundstrom (2018) examined the cost of illness from five foodborne diseases (campylobacteriosis, salmonellosis, enterohemorrhagic Escherichia coli (E. coli) (EHEC), yersiniosis, and shigellosis). Results showed that campylobacteriosis represented 69 per cent of the combined cost of these diseases. This is followed by salmonellosis (18 per cent), EHEC (9 per cent), then yersiniosis and shigellosis (2 per cent, each). These results have been supported by similar findings across the literature (ANU, 2022; Lake et al., 2010; Painter et al., 2013; Gadiel, 2010). This further suggests that costs may differ for food safety responses to different pathogens in the supply chain. Also, different food products carry higher risks for foodborne illness and subsequent impacts than others. For example, poultry is frequently cited as a common source of foodborne illness and associated negative impacts (Painter et al., 2013; Soon et al., 2020).

Another important consideration is that there may be hidden costs involved in estimating the total costs of foodborne illness. Actual infection rates from foodborne illness may differ from reported case numbers due to information loss, suggesting that there may be higher costs from food safety outbreaks than those reported. For example, Sundstrom (2018) used sequential multipliers to estimate unreported case numbers from five major foodborne illnesses and sequelae[1] (campylobacteriosis, salmonellosis, EHEC, yersiniosis and shigellosis) in Sweden. This showed that the total estimated number of cases were between 7- and 11-fold higher than those reported with an actual total annual cost of €142 million. In addition, the analysis found that sequelae represented approximately 50 per cent of the total costs of each pathogen (Sundstrom, 2018). This suggests that estimates in the literature may underestimate the actual cost of foodborne illness overall.

2.1.3 The total costs of food safety incidents

Some studies have estimated the total annual costs of foodborne illness more broadly. These have included economy-wide analyses of the various measurable aspects of food safety incidents. The studies often assess multiple foodborne illnesses and their associated sequelae. For example, in the US, Minor et al. (2015) estimated that foodborne illness and sequelae represent an annual burden to society of approximately US$36 billion, with an average illness reducing QALYs by 0.84, representing an average per-person cost of illness of US$3,630 each year (Minor et al., 2015). Similarly, Scharff (2012) estimated the total annual economic burden of foodborne illness in the US using two models – *basic* (including medical costs, productivity losses and illness-related mortality) and *enhanced* (replacing productivity loss estimates with pain, suffering and functional disability measures). The results showed annual cost of foodborne illness of US$1,068 per person under the *basic* model and US$1,626 under the *enhanced* model. Total economic costs were estimated at US$51 billion under the *basic* model and US$78 billion under the *enhanced* model (Scharff, 2012).

In addition, some authors have combined metrics for annual costs of foodborne illness. For example, Hoffman et al. (2012) estimated the total annual costs of 14 pathogens in the US using a combination of monetary values - COI and QALYs. Results estimated a COI of US$14 billion and a loss of 61,000 QALYs as from the 14 pathogens. The authors found that 90 per cent of these losses were caused by five pathogens: (1) non-typhoidal Salmonella (US$3.3 billion p.a., 17,000 QALYs); (2) Campylobacter (US$1.7 billion p.a., 13,300 QALYs); (3) Listeria monocytogenes (US$2.6 billion p.a., 9,400 QALYs); (4) Toxoplasma gondii (US$3 billion p.a., 11,000 QALYs); and (5) Norovirus (US$2 billion p.a., 5,000 QALYs). This work was expanded with a companion study that estimated losses based on specific food categories and pathogens, including QALY losses associated with each given pathogen (Batz et al., 2012).

In New Zealand, Lake et al. (2010) estimated both the COI and DALYs, as well as Years of Life Lost (YLL), from six foodborne illnesses between 2000 and 2005. These included (1) campylobacteriosis, (2) salmonellosis, (3) listeriosis (perinatal and non-perinatal), (4) Shiga-toxin producing Escherichia coli (E. coli) (STEC) infection, (5) yersiniosis and (6) Norovirus. Results are summarised in Table 2-4. This shows

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[1] Sequelae is a condition which is the consequence of a previous foodborne illness.

that campylobacteriosis and sequelae are associated with the highest COI (NZ$74 million) and DALYs (880) over the 5-year period (Lake et al., 2010).

Table 2-4: Cost of foodborne illnesses in New Zealand, 2000-2005.

Foodborne Illness	**Food-Attributable COI** NZ$ million (Range)	**Food-Attributable DALYs** Mean (Range)
Campylobacteriosis and sequelae	74 (51-102)	880 (550-1,240)
Salmonellosis and sequelae	2.8 (1.9-4.0)	111 (53-201)
Listeriosis (perinatal)	2.3 (0.7-4.8)	195 (101-307)
Listeriosis (non-perinatal)	0.2 (0.1-0.5)	22 (7-54)
STEC infection and sequelae	1.6 (0.06-4.8)	35 (0.4-109)
Yersiniosis and sequelae	1.4 (0.9-2.0)	52 (21-93)
Norovirus infection and sequelae	3.0 (0.7-11)	210 (41-546)
Total	**86** **(61-115)**	**1,510** **(740-2,780)**

Source: Adapted from Lake et al., (2010).

Australian National University (ANU, 2022) estimated the annual costs of foodborne illness in Australia, including associated sequelae. Results showed a total cost of AU$2.44 billion per annum. These costs are summarised in Table 2-5. As with previous studies, the researchers found that the highest costs incurred from Campylobacter (AU$365 million per year), while Norovirus, other pathogenic E. coli and Salmonella were all estimated to cost over AU$100 million annually. Listeria had the highest per case cost at AU$785,000 per case (ANU, 2022).

Table 2-5: Annual costs of foodborne illness, Australia.

Pathogen	Number of cases	Cost per case in AU$	Median costs in AU$ '000	
			Cost of initial illness	Cost of illness and sequelae
All foodborne pathogens	4,680,000	526	2,200,000	2,440,000
Total gastroenteritis	4,670,000	507	2,100,000	2,350,000
Campylobacter	264,000	1390	179,000	365,000
Listeria monocytogenes	101	785,000	78,400	No sequelae
Non-typhoidal Salmonella	61,600	2,270	103,000	140,000
Norovirus	328,000	396	128,000	No sequelae
Shigella	1,930	1,740	2,310	3410
Shiga-toxin producing E. coli (STEC)	2,630	4,330	2,470	11,700
Other pathogenic E. coli	312,000	422	133,000	No sequelae
Salmonella Typhi	28.6	15,100	468	No sequelae
Toxoplasma gondii	15,500	840	13,100	No sequelae
Yersinia enterocolitica	7,170	1,430	7,480	10,400

Source: Adapted from ANU, (2022).

Many studies have estimated the total costs of a specific food safety outbreak. For example, Thomas et al. (2015) estimated the total costs from a Listeria outbreak from processed meat in Canada in 2008. Results estimated the total costs from this at CA$242 million. This comprises CA$162 million for all cases (including mortality), CA$2 million in federal outbreak response costs, and CA$77 million in total costs for the implicated meat processing facility. Similarly, Olanya et al. (2019) estimated the total costs associated with foodborne listeriosis outbreak in South Africa in 2017. The researchers estimated the total economic costs at around US$13 million (Olaynya et al., 2019).

2.2 Social costs

Wider society bears costs and impacts associated with food safety incidents. These include (but are not limited to): mortality, illness (including acute and chronic illness) and impacts of quality of life (e.g. chronic health impairments, disability); food security risks; a range of private and public costs (e.g. healthcare); and productivity loss. This section provides an overview and analysis of existing literature examining the social costs of food safety incidents.

2.2.1 Mortality

The greatest potential social impact as a result of food safety outbreaks is that of human mortality from the consumption of affected food products. As mentioned in Chapter 1, the WHO has estimated that there are approximately 600 million cases of foodborne illness internationally each year, resulting in approximately 420,000 deaths globally each year, or roughly 7.5 per cent of all global causes of death worldwide (Lee and Yoon, 2021; WHO, 2022a). This represents a loss of approximately 33 million years of healthy life, with this number likely to be an underestimate (WHO, 2022a).

Several studies have estimated the number of deaths caused by foodborne illness in different countries. For example, Thomas et al. (2015) estimated the number of hospitalisations and deaths attributed to 30 specific pathogens and unspecified agents from food safety incidents in Canada. The authors estimated average annual rates of 4,000 hospitalisations and 105 deaths from foodborne illness caused by 30 pathogens, and a further 7,600 hospitalisations and 133 deaths from unspecified agents. This totals to 11,600 hospitalisations and 238 deaths each year from foodborne illness in Canada (Thomas et al., 2015).

Similarly, Painter et al. (2013) estimated the attribution of foodborne illnesses to hospitalisations and deaths in the US by commodity and pathogen agent type (bacterial, chemical, parasitic, and viral) between 1998 and 2008. The authors found foodborne illness to be associated with 57,462 hospitalisations and 1,451 deaths during that period. The majority of these are caused by bacterial agents (35,797 hospitalisations and 862 deaths), followed by parasitic (4,886 hospitalisations and 333 deaths), viral (15,284 hospitalisations and 156 deaths), and chemical agents (1,496 hospitalisations and 100 deaths). In addition, the authors found that approximately 46 per cent of all illnesses were associated with food consumption, and more deaths were associated with poultry consumption than any other product examined (Painter et al., 2013).

The number of deaths associated with food safety outbreaks depend on the specific illness or pathogen involved. Some illnesses carry a greater risk of mortality than others. This has been demonstrated across the international literature. For example, Scallan et al. (2011a) estimated mortality rates in the US associated with 31 major pathogens between the years 2000 and 2008. Results showed that these pathogens were responsible for 1,351 annual deaths from foodborne illnesses. The authors also found that the pathogens most commonly responsible for mortality were non-typhoidal Salmonella spp. (28 per cent), Toxoplasma gondii (24 per cent), Listeria monocytogenes (19 per cent), and Norovirus (11 per cent) (Scallan et al., 2011a). In another study, Scallan et al. (2011b) estimated mortality rates in the US associated with unspecific agents from foodborne illness. Results showed that unspecific agents in food safety incidents may be responsible for around 1,686 deaths annually in the US (Scallan et al., 2011b). Similarly, Hall et al. (2005) estimated the number of cases, hospitalisations and deaths caused by foodborne gastroenteritis in Australia in 2000. The authors estimated that there were 17.2 million cases of gastroenteritis in Australia in that year, 32 per cent of which were foodborne, equating to 5.4 million annual cases, causing 15,000 hospitalisations, resulting in 80 deaths per year (Hall et al., 2005).

A number of studies have estimated the cost of mortality. For example, Olanya et al. (2019) estimated the total cost of mortality associated with a foodborne listeriosis outbreak in South Africa in 2017. This outbreak caused the death of 204 South Africans, with estimates of total costs ranging between US$253.9 million and US$515 million. Per case costs ranged between US$1.2 million and US$2.5 million (Olanya et al., 2019). Hoffmann et al. (2012) estimated the total annual costs associated with deaths caused by 14 pathogens in the US to be approximately US$11 billion for acute cases and US$740 million for chronic conditions.

2.2.2 Health and quality of life

Food safety incidents carry the risk of causing illness and reducing the quality of life of those affected. This can be short- or long-term (chronic) illness. In this report, short-term illness is described as an illness directly related to the food safety incident that is expected to be temporary. Short-term illnesses can be primary (a direct result of the food safety incident) or secondary (induced as a consequence of the primary illness or otherwise related to the food safety incident; this is also known as sequelae). In contrast, long-term or chronic illness induced by a food safety incident is described as an illness that is expected to remain with the affected person, either for a long period of time or the rest of their life. An example of a sequelae from campylobacteriosis in which an affected person may become sick with a short-term acute gastrointestinal illness which may then lead to a longer-term chronic illness such as Crohn’s Disease (Cressey and Lake, 2008).

Food safety incidents may also affect consumers’ quality of life through impairment or distress. This is often captured and valued in the literature through the use of the QALY metric. For example, Hoffmann et al. (2012) measured the QALY losses associated with 14 foodborne pathogens in the US, taking into account the effects on quality of life for those affected, including mobility, self-care, ability to perform usual activities, pain/discomfort, and anxiety/depression. As shown in Table 2-6, the authors found specific pathogens to have different severities of QALY losses, ranging between 10 QALYs (Cyclospora cayetanesis) and 13,256 QALYS (Campylobacter). These differed depending on the level of severity of illness and whether the illness was chronic or acute.

Table 2-6: Annual QALY losses associated with 14 pathogens in the United States.

Pathogen	**Mean total QALY loss (low-high)**	**Mean QALY loss: acute cases**				**Mean QALY loss: chronic conditions**	
		Mild (no doctor visit)	*Moderate (doctor visit)*	*Severe (hospitalization)*	*Death*	*Morbidity*	*Death*
Campylobacter spp.	13,256 (7,993-26,021)	234	97	66	2,664	6,814	3,380
Clostridium perfringens	875 (83-3,942)	310	108	2	456	0	0
Cryptosporidium parvum	341 (40-1,265)	30	7	2	150	151	0
Cyclospora cayetanesis	10 (0-33)	6	4	0	0	0	0
E. coli O157:H7	1,660 (131-7,7872)	9	47	23	1,238	28	314
STEC non-O157	153 (10-268)	16	85	3	0	4	45
Listeria monocytogenes	9,375 (1,531-23,525)	0	0	44	8,532	799	0
Adult	4,595	0	0	33	4,562	0	0
Congenital	4,780	0	0	11	3,970	799	0
Norovirus	5,027 (2,897-7.832)	1,747	610	54	2,612	0	0
Salmonella nontyphoidal	16,782 (304-44,380)	276	100	152	16,254	0	0
Shigella spp.	545 (14-3,372)	43	22	7	473	0	0
Toxoplasma gondii	10,964 (6,026-16,771)	0	11	64	10,101	789	0
Adult	9,323	0	11	64	9,062	186	0
Congenital	1,642	0	0	0	1,038	603	0
Vibrio vulnificus	557 (294-882)	0	0	2	555	0	0
Vibrio spp. Other	210 (60-595)	13	9	3	185	0	0
Yersinia enterocolitica	1,415 (13-8,216)	25	17	13	1,360	0	0
TOTAL	**61,166 (19,397-144,974)**	**2,710**	**1,118**	**434**	**44,579**	**8,585**	**3,739**

Source: Hoffmann et al., (2012).

In order to effectively compare estimates, some studies have estimated the costs of foodborne illnesses on quality of life. Scharff et al. (2009) examined the cost of foodborne illness in Ohio, USA in 2007. In their study, the researchers estimated the quality from health impacts for a series of known pathogens and unknown agents. The authors found that different foodborne pathogens produced different effects on quality of life, with estimates ranging between US$327 (for both Bacillus cereus and Clostridium perfringens) and US$10,164 (foodborne botulism) per case (Scharff et al., 2009).

2.2.3 Public and private costs

There are many public and private costs associated with food safety outbreaks. These include (but are not limited to) costs associated with healthcare, particularly hospitalisation. Several studies have included rates of hospitalisation from foodborne illness. For example, Hoffmann et al. (2012) estimated the annual COI (in 2009 prices) from 14 foodborne illnesses in the US, including those cases requiring healthcare. For moderate cases (requiring a doctor’s visit), the total estimated cost was US$445 million per annum. For severe cases (requiring hospitalisation), the total estimated annual cost was US$1 billion (Hoffman et al., 2012).

Gadiel (2010) estimated the total cost of foodborne illness in New Zealand in 2009, including the cost of treatment. This included costs associated with general practitioner (GP), specialist and other health services, medicines, laboratory testing, inpatient hospital care, and associated transport costs. Results are shown in Table 2-7. This shows a total cost across all selected pathogens of NZ$5 million during 2009, NZ$1 million after 2009, leading to total lifetime treatment costs of NZ$6 million. However, it should be pointed out that estimated per case treatment costs ranged considerably from NZ$10 per case for Norovirus to NZ$32,318 per case for listeriosis (Gadiel, 2010).

Table 2-7: Estimated treatment costs from foodborne illness in New Zealand (2009).

Disease	No. of incident cases	Cost during 2009 (NZ$ millions)	Cost after 2009 (NZ$ millions)	Unit treatment cost per case (NZ$)	Total lifetime treatment cost (NZ$ millions)
Campylobacteriosis	41,262	2.13	0.04	52.69	2.17
Salmonellosis	2,741	0.19	0.00	71.23	0.20
Norovirus	138,204	1.45	0.00	10.49	1.45
Yersiniosis	4,699	0.12	0.00	24.53	0.12
STEC	210	0.38	1.17	7,202.38	1.51
Listeriosis	23	0.74	0.00	32.313.38	0.74
TOTAL	**187,139**	**5.01**	**1.18**	**33.08 (av.)**	**6.19**

Source: Gadiel, (2010).

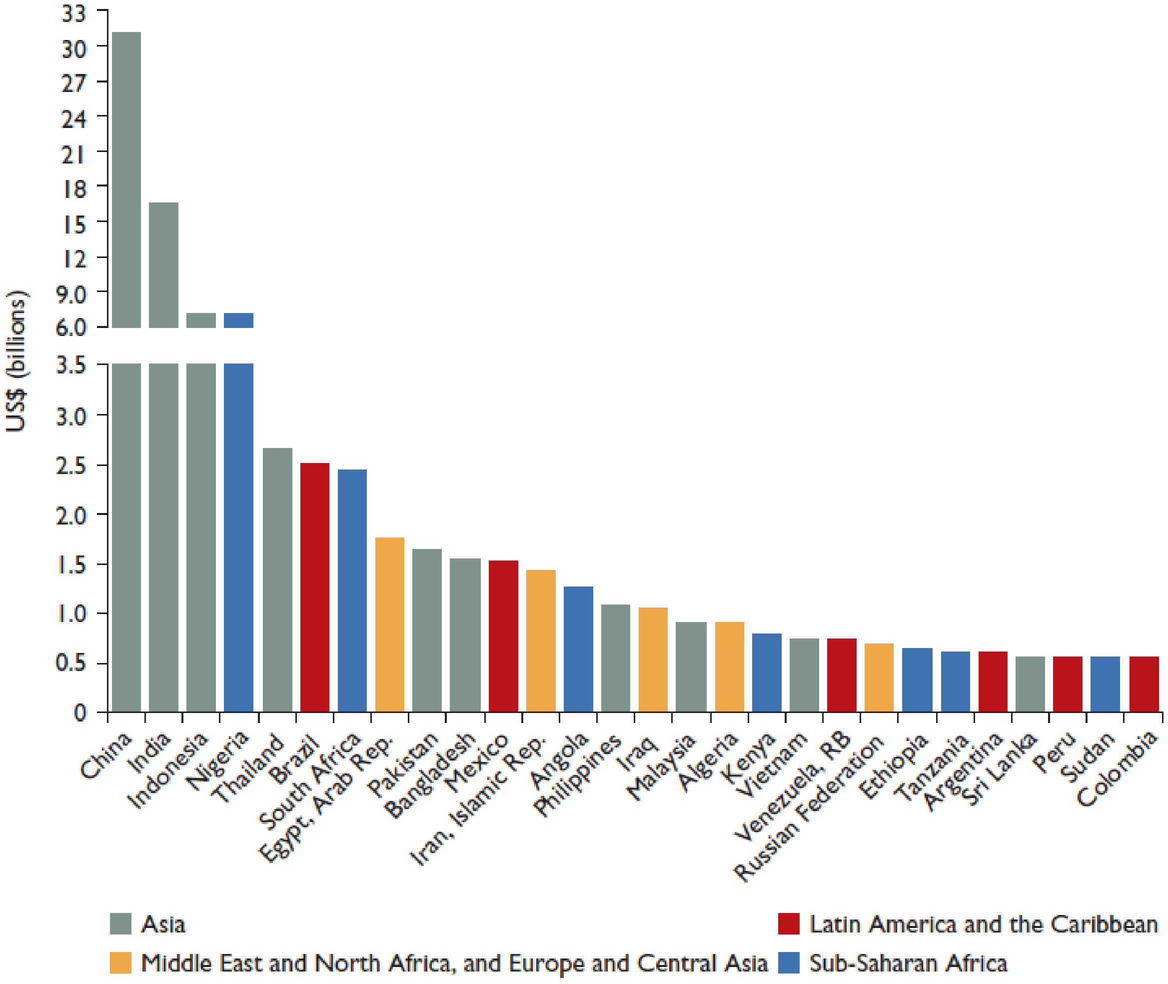
Olanya et al. (2019) examined the costs of hospitalisation in relation to a Listeria outbreak in South Africa in 2017. For the 1,034 affected South Africans requiring hospitalisation, the estimated total cost was US$10.4 million. Per case cost estimates varied based on the patients’ age. Hospitalised babies were estimated to cost around US$15,840 per case, while older individuals were estimated to cost US$7,920 per case (if they passed away as a result of their illness) or otherwise US$3,960 per case (Olanya et al., 2019).

2.2.4 Productivity loss

Food safety incidents also often incur loss of productivity over the lifespan of affected persons often during the period of illness. As seen above, the average duration of foodborne illnesses in those affected varies depending on the pathogen involved. As estimated by Major et al. (2015), the average number of days ill for common foodborne illnesses varies between 1 and 270 days. These can differ considerably depending on whether an affected person is hospitalised as a result of their illness. This is further affected by the possible incidence of sequelae which has been estimated between 11 and 15,695 ill days, depending on the pathogen involved (Major et al., 2015).

The WHO (2018) has estimated the cost of productivity loss from foodborne diseases by group, region and country in 2016. Human capital loss as a result of foodborne disease was US$3.8 billion for those in the low-income group, US$40.6 billion for those in the low-middle income group, and US$50.8 billion for those in the upper-middle income group. The combined value was US$95.2 billion in 2016. By region, the highest human capital losses were seen in Asia (US$63.1 billion, 66 per cent), followed by Sub-Saharan Africa (US$16.7 billion, or 18 per cent), the Middle East and North Africa, and Europe and Central Asia (US$7.9 billion, 8 per cent), and Latin America and the Caribbean (US$7.4 billion, 8 per cent). Furthermore, Figure 2-1 shows WHO estimates of the relative cost of productivity loss by country as a result of foodborne disease, indicating that China and India bearing the highest relative costs (WHO, 2018).

Figure 2-1: Relative cost of productivity loss by country, 2016.



Source: WHO, (2018).

A range of studies have estimated the value of productivity loss from foodborne illness. For example, Scharff et al. (2009) estimated the cost of productivity loss from foodborne illness in Ohio, USA in 2007. Results estimated productivity loss at US$66 per person per ill day. Similarly, Thomas et al. (2015) estimated the costs from a Listeria outbreak from processed meat in Canada in 2008. Productivity loss was estimated at CA$26,845 per case. Olanya et al. (2019) valued the cost of productivity loss from a Listeria outbreak in South Africa, estimating total productivity loss at over US$15 million, or US$184,276 per case (2003 values).

In summary, costs from foodborne incidents and illness vary considerably depending on many factors, i.e. the pathogen involved, the length of illness, required treatment/ hospitalisation, among others.

2.3 Economic costs

Food safety outbreaks can potentially lead to significant economic costs for companies, the food industry, and the economy as a whole. These costs may include:

- Medical treatment coverage of affected consumers and potential compensation;
- Costs to comply with regulations;
- Costs for tracing back contamination(s);
- Product recalls;
- The discarding of potentially contaminated food;
- Plant closure and cleaning;
- Product liability;
- Regulatory and legal response (including penalties, fines, lawsuits and legal fees);
- Higher insurance premiums;
- Trade impacts;
- Marketing and advertising (to restore reputation); and
- Prolonged effects on the market due to reputational damage.

Economic losses can be severe if food products are removed from domestic or export markets due to food safety concerns. This has the potential to lower market value and/or traded volumes. Further, this can potentially reduce employment and livelihood with potential secondary impacts along the supply chain on producers, processors and/or distributers. This may even reduce the livelihood of communities and impact on non-food sectors, e.g. tourism (FAO, 2017).

Economic costs related to food safety outbreaks can be split into direct and indirect costs, where the direct costs include costs for notifying consumers, recalls, and lawsuits due to food safety incidents, and the indirect costs include the prolonged effect on the market due to reputation damage, market prices, and similar.

Internationally, many studies exist focussing on estimating the direct economic costs of specific food safety incidents. For example, in the US in 2008/ 2009 there was a significant Salmonella outbreak of *Peanut Corporation of America* during which 714 people fell ill of which nine people died. This outbreak incurred significant economic costs of over US$1 billion (*Peanut Corporation of America* had an annual revenue of around US$25 million). Peanuts are an ingredient in many other products. *Kellogg's* alone estimated its loss at US$65–70 million from product recall from this outbreak, and the company is only one of many *Peanut Corporation of America* customers (Regusci, 7 Jan 2022).

Food recalls can also impact a whole industry. In 2006, there was a large E. coli outbreak in spinach in California, USA from one single farm. However, the impact on the spinach industry was estimated at a loss of more than US$200 million in retail sales and many more millions in opportunity sales from the outbreak (Regusci, 7 Jan 2022).

A more recent outbreak was the 2018 outbreak of E. coli in romaine lettuce from a single farm in California, USA. The food recall lasted for several weeks. In their study, Spalding et al. (2022) estimated the cost of this incident at US$300 million. Economic losses incurred mostly for romaine shippers, processors, and grocery retailers who had to take the product from the supply chain and lost sales due to reduced consumer demand. These widespread and prolonged impacts from a food safety incident demonstrate the economic benefit for industries adopting food safety standards and improved traceability to minimise the occurrence and scale of impacts of such incidents (Spalding et al., 2022).

In 2013, there was suspected contamination of the Clostridium botulinum in a concentrated-whey product (infant formula) distributed to food suppliers in numerous countries by Fonterra in New Zealand. This particular bacterium is known to cause botulism, a severe and deadly form of food poisoning. Within hours of the announcement of the potential contamination in its products, the estimated loss for Fonterra was more than NZ$60 million. The incident also caused short-term trade disruptions with countries such as China, Russia and Sri Lanka imposing a temporary ban on some dairy products from New Zealand. Danone (Paris, France), one of the customers who received the food safety alert, sought €200 million (NZ$270 million) in compensation from Fonterra to cover the costs associated with the product recall as a result of the incident. Arbitration required Fonterra to pay Danone a total of €105 million (NZ$183 million) in recall costs. Further, through the Wellington District Court in New Zealand, Fonterra has been fined NZ$300,000 after the company admitted four food safety violations during the scare (BBC.com, 4 Apr 2014; Fonterra, 2017; Hussain and Dawson, 2013). In the following sections, this specific food safety incident is referred to as the WPC80 incident (Government Inquiry into the Whey Protein Concentrate Contamination Incident, 2014).

Some studies have estimated the total (annual) costs from foodborne diseases more broadly. These have included national economy-wide analyses of the various measurable aspects of food safety incidents, often assessing a number of foodborne illnesses and their sequelae. Gadiel (2010) prepared a study for the New Zealand Food Safety Authority (NZFSA) in which he estimated the economic costs of the following six foodborne diseases: (1) campylobacteriosis (2) salmonellosis (3) Norovirus (4) yersiniosis (5) Shiga-toxin producing E. coli (STEC) (6) listeriosis for New Zealand. As show in Table 2-8, the estimated total costs to the economy were NZ$161.9 million in 2009. This includes government outlays of NZ$16.4 million, industry costs of NZ$12.3 million and NZ$133.2 million for incident case costs of disease associated with treatment, output loss and residual lifestyle loss.

Table 2-8: Summary of total costs of foodborne diseases in New Zealand, 2009.

Type of cost	**NZ$ million**	
Government outlays	16.4	
Industry costs	12.3	
Subtotal, government and industry costs		28.7
Treatment Costs	6.19	
Output loss (incl. losses by households)	27.32	
Residual private costs	99.67	
Subtotal, incident case costs		133.19
Grand Total		**161.9**

Source: Gadiel, (2010).

Some studies have estimated the indirect costs of food safety incidents. For example, Houser and Dorfman (2019) showed that beef recalls in the US had a prolonged effect on cattle prices for at least two years. In addition, Lloyd et al. (2001) showed that the drops in prices caused by a food safety incident vary for different actors along the supply chain. In their study, the researchers found a negative impact on the prices at retail, wholesale, and producer level from the Bovine Spongiform Encephalopathy (BSE) crisis in the UK in the 1990s. The study showed that the decline of beef prices at farm level were higher than those at retail level (Lloyd et al., 2001). This is in line with Popovic et al. (2017). Their study showed a significant decrease of dairy prices at farm-level after the Aflatoxin[2] M1 incident in Serbia between 2012 and 2014. Study results suggested that the Aflatoxin outbreak temporally reduced Serbian market integration with the world dairy market, causing losses for the domestic dairy supply chain (Popovic et al., 2017). Palma et al. (2010) analysed the potential impacts of food safety outbreaks on domestic shipments, imports, and prices of the US food industry from three case studies (1) the cantaloupe outbreak in 2008, (2) the spinach outbreak in 2006 and the (3) tomato outbreak in 2008. It was estimated that the short-term farm level impact on US spinach was a loss of over US$8 million with domestic shipments of spinach falling by 7,088 metric tons. The losses from the tomato outbreak were even higher with farm losses estimated at US$25 million. Finally, short-term farm-level cantaloupe losses were estimated at US$5.8 million for the domestic market and US$29.5 million for imports, because the contamination source was found to be foreign (Palma et al., 2010).

Food safety incidents that lead to health issues generate externalities. An externality is a cost or benefit caused by a producer that is not financially incurred or received by that producer. The costs of these problems caused by a food safety incident are often not paid fully by the party that caused it. While parties responsible for the food safety incident may be required to pay some of the costs, they are rarely penalised through the courts. Mahdu (2015) described that between 1979 and 2014, at least 512 food-borne illness cases were resolved through the US court system. Of these cases, about one third resulted in monetary compensation to plaintiffs, with average compensation of US$276,000. Plaintiffs' total nominal compensation was US$49.2 million in that time period. This is low considering that millions of cases of foodborne illness cause an estimated public cost of over US$15 billion annually in the US (Mahdu, 2015; Hoffmann et al., 2015). In addition, Bovay (2022) argued that the threat of legal liability does not seem to function as prevention of food safety incidents as it has not historically been economically meaningful. Another example is *Chipotle.* In 2021 the company agreed to pay the largest fine in US history of US$25 million for its share in multiple *E. coli* outbreaks from 2015 to 2018. The fine is small compared to the stock market loss. In 2015, the stock went from US$740 per share to a low of US$250, and only by mid-2019 did the company's stock return to US$740 with many market opportunities lost. While *Chipotle* has a lot of resources to manage and recover from this incident, many small companies went bankrupt and were forced to close down over this outbreak (Regusci, 7 Jan 2022). A more severe sentence was imposed on the people responsible for the above described Salmonella outbreak of *Peanut Corporation of America* in 2008/2009 where 714 people fell ill and nine people died. For this outbreak, three executives went to jail for more than 20 years because they knew that they were shipping salmonella-tainted peanut butter and tried to cover it up (Basu, 21 Sept 2015; Flynn, 18 Oct 2022).

2.3.1 Food recalls and traceability

Food safety recalls have increased significantly in recent years, and they directly impact the whole sector. A product recall can result in serious long-term financial damage for a company due to loss of sales, consumer trust and loyalty (see Figure 2-2). Hence, stakeholder responses to food safety incidents can cause significant economic losses for food companies. There is also evidence on lost firm profitability as reflected by the reduction in stock market value of firms after recalls (Pozo and Schroeder 2016; Ollinger and Houser 2020). The Grocery Manufacturers Association (GMA, 2011) in the US reported that direct

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[2] Aflatoxins M1 are mycotoxins. They are carcinogenic to animals and perhaps humans.

recall costs (i.e., retrieval, destruction, reimbursement etc.) to large food companies were around US$10–29 million per recall. However, the indirect costs of reputation damage and liability may be higher (Roberts, 2004; Shavell, 1984). Those costs and the recovery costs are reflected in stock market losses (Pozo and Schroeder, 2016). In their study, Pozo and Schroeder (2016) showed that on average, shareholders' wealth is reduced by 1.15 per cent (equivalent to US$109 million) within 5 days after a recall involving a serious food safety incident. However, stock markets do not react negatively when recalls involve less severe incidents. The researchers concluded that the economic impact of the recall depends on the company's size and their experience in handling a recall, media information and recall size. Hence, understanding the likely impact of food recalls is critical for companies investing in food safety protocols and technologies (Pozo and Schroeder, 2016).

Costs of food recalls increase over time. In their study, Velthuis et al. (2009) demonstrated the relation between recall costs and time using an example of direct recall costs along the milk chain in the Netherlands. The researchers estimated that the direct recall costs of recalling a batch of milk of 150,000kg were less than €100,000 in the first 16 hours after the milk has been collected from the farms, however the costs increased rapidly to more than €140,000 along the supply chain. The researchers emphasisd the importance of the development of monitoring schemes at individual stages of the supply chain (Velthuis et al., 2009).

Figure 2-2: Impact of food recalls.

Source: Food Safety Magazine, (2012).

Traceability is essential to the protection of the food industry's reputation by isolating products from the source of the problem. Bovay (2022) pointed out that reputation damage also affects producers and products that are not are not liable for the food safety incident. He stressed the importance of accurate and fast traceability which would reduce this misattribution and reputational spillovers to the whole industry. Further, food safety recalls and scares have often led to significant reduction in product demand, and Bovay (2022) argued that negative demand shocks appear to be the major incentive for producers to implement traceability systems into their production.

2.3.2 Trade costs

International trade of agricultural commodities is extensive and growing continuously. Any trade poses some risk of introducing new foodborne pathogens into countries. Hence, local food safety outbreaks can turn into international emergencies due to the speed and range of product distribution. Each year, a proportion of food exports are rejected by importing countries due to contamination. Economic consequences from these rejections are likely to be substantial. However, there is a lack of data on the total annual volume and economic impact of rejected international shipments for food safety reasons, either for individual countries or for all countries combined. This is highly sensitive data because this information could jeopardise ongoing trade negotiations (Buzby and Roberts, 1997). For example, in 2012 9.6 tons of Evian mineral water (owned by Danone) were rejected by Beijing, China and were shipped back because excessive nitrite was found in the imported mineral water (Beibei, 5 Jun 2012; China.org.cn, 4 Jun 2012). Also, during the above mentioned WPC80 incident in 2013, several countries (China, Russia and Sri Lanka) imposed a short-term export ban on some dairy commodities from New Zealand (Hussain and Dawson, 2013). In their study, Stojkov et al. (2016) analysed the trade impacts of the incident. Results showed there was no significant long-term impact on the total value of most dairy exports (i.e., skim milk powder, whole milk powder, butter and cheese) from the incident. However, results further demonstrated significant long-term negative impact on whey products and infant formula. The researchers claimed that by 2015 exports of these products have not returned to levels from before the incident (Stojkov et al., 2016).

2.3.3 Compliance costs

There are costs associated with the compliance of food safety standards. Compliance with food safety standards can be mandatory, i.e. dictated by domestic government, regulations by importing countries or it can be voluntary through national and/or international assurance schemes such as GlobalGAP, BRC Global Standards etc. It is important for organisations to outweigh the costs and benefits to be in compliance with food safety standards. Benefits accrue over time and are uncertain while the costs of compliance are upfront and in many cases are required to participate in a preferred export market. For example, Ribera et al. (2012) showed that after the E. Coli spinach outreak in California, USA in 2006, many spinach producers joined the California Leafy Greens Marketing Agreement (LGMA), a food safety scheme with specific requirements for producers of leafy greens. The LGMA Standard is designed to minimise the potential for such an outbreak. In 2010, LGMA compliance costs were US$604,000 compared to estimated outbreak costs of US$12 million at farm level and US$63 million at retail level. Clearly, in this food safety incident the compliance costs were much lower than the escalating costs from the outbreak. Ribera et al. (2012) concluded that the costs for producers from food safety outbreaks in produce are far greater than preventing such incidents.

In their study, Song and Chen (2010) examined the costs of China's agri-food exporting companies in complying with overseas market access requirements. Using aggregate trade data, study results demonstrated that overseas market access requirements had a significantly negative effect on China's short-run exports, while they had a positive effect on China's long-run exports in agricultural products. Further, results showed that total compliance costs increased annually. The main components of compliance costs included building renovations, technological innovations and testing. The researchers further demonstrated that compliance costs of domestic private enterprises were more than that of foreign-funded enterprises. In all types of certifications, the highest amount of compliance cost was HACCP certificate. The cost of obtaining ISO9001[3] certificate was less than that of HACCP certificate. GAP-Global certificate costs were the smallest (Song and Chen, 2010).

2.3.4 Reputational impacts and spillover effects

Food safety outbreaks can have a prolonged effect on the market due to reputation and brand damage of the company with a food safety incident. These indirect costs are often more severe than the direct costs from a food safety incident as they usually last longer. These indirect costs are also more difficult to measure. Companies may face substantial profitability losses if the food safety incident causes reputation damage and hence reduces the long-term demand for their products (Pozo and Schroeder, 2016). In these

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[3] ISO 9001 sets out the criteria for a quality management system.

cases, expensive marketing campaigns are often required to recover the company's reputation (Law and Cornelsen, 2022).

Some studies exist examining consumer response to food recalls, reputational damage and spillover effects. In particular, the impact to the company's market value and brand reputation was investigated in some studies. Law and Cornelsen (2022) examined the long-term impact of food recall on product sales in India. Their study focussed on noodle purchases after the nationwide removal of Maggi instant noodles from the domestic market in 2015. In June, Maggi noodles were recalled and temporarily banned across the country due to the controversy over its excessive level of lead and the presence of monosodium glutamate (MSG) even though the product label stated 'no added MSG'. Within one month, the sales of Maggi noodles decreased by 90 per cent and 400 million packets of Maggi noodles were discarded. These products were only reintroduced into the market four months later. Law and Cornelsen (2022) found that this recall had a negative impact on the purchases of Maggi noodles among urban households for at least two years. While Maggi had regained status as the leading noodle brand by April 2016, its market share in India only recovered to 50 per cent, which was considerably lower than the 70 per cent prior to the scandal (Law and Cornelsen, 2022).

Further, studies have shown that a product recall can create an increase in demand for unimplicated products (Bovay, 2022). In the above described Maggi noodles scandal in India assessed by Law and Cornelsen (2022), the researchers also showed how Indian consumers made permanent changes to their purchase patterns in response to food safety concerns even if that food product played an important role in their diet and food culture. Their analysis demonstrated strong evidence for a positive spillover effect to non-Maggi noodles. This shows that food safety concerns could have a positive effect for other brands to capture market share and build brand loyalty. This is in line with Bakhtavoryan et al. (2014), their study also showed that the food recall of a particular brand generated increased consumer demand for brands that were not recalled.

Also, Marsh et al. (2004) showed that product recalls directly impact the sector. The researchers found a negative effect from meat recalls on the demand for the affected meat products. They also showed that those events generated increased demand for their substitutes, which were however, offset by an overall decrease in meat demand. Meat recall information significantly impacted demand for beef and pork in current and lagged periods, wearing off after three quarters. The general effect indicated a shift away from meat to other food products. Similar substitution effects were also shown by Tonsor et al. (2010). The researchers showed that beef recalls in the US had a negative effect on beef demand but a positive effect on poultry demand during three-quarter period following recalls. Similarly, Arnade et al. (2009) investigated consumer response to the recall of spinach products due to the outbreak of E. coli in the US in 2006. Using national weekly retail scanner data, they demonstrated that the recall led to purchases shifting from spinach products to bulk lettuce of all types. However, this resulted in no long-term change in the demand for leafy greens as a whole (Arnade et al., 2009).

Some studies suggest ways of how to minimise negative reputation effects after a food recall. Onyango et al. (2007) pointed out that public education and outreach efforts on overall food safety may change the public perceptions on food safety after a recall. For the US E.coli outbreak in spinach in 2006, the researchers showed that that low levels of objective knowledge about food pathogens and the resulting illnesses may lead to the public perceiving that all food may be unsafe for consumption. They pointed out that public views on food corporations (processors, transporters or retailers) impacted food safety perceptions negatively. On the other hand, confidence in the United States Department of Agriculture (USDA) as a regulatory agent was viewed positively and hence contributed toward viewing the four types of spinach as safe for consumption (Onyango et al., 2007).

Further, Kong et al. (2019) concluded that government and regulators should strengthen the monitoring of food safety to ensure the quality of food. The authors claimed that this would improve the quality of residents' life and reduces economic impacts from food safety outbreaks such as stock fluctuation (Kong et al., 2019).

To conclude, a large body of literature exists that examines the costs for society and the economy caused by food safety incidents. These costs vary depending on many factors, including the type of pathogen involved, the region affected, the breadth and severity of the incident, as well as the company's and industry's response. Social costs include mortality, illness, disability, reduced quality of life, as well as public costs, such as the cost of hospitalisation or lost productivity. Food safety outbreaks can also generate economic costs for actors along the food supply chain, including (but not limited to) producers, processors, retailers, distributors, exporters and consumers, as well as to society and the economy as a whole. These costs can include (but not limited to) the cost of incident response, lost revenue and additional costs to food firms, as well as reputational damage and prolonged market effects. However, it is difficult (and maybe even impossible) to factor all possible costs associated with food safety outbreaks due to their far-reaching and complex nature, meaning that any quantification of the costs of food safety events is likely to be a gross underestimate.

Chapter 3
The Value of Food Safety Science

Science for food safety is a critical part of national food control systems designed to prevent or mitigate food safety outbreaks. Scientific testing is required across multiple stages of food safety control in order to protect public health, comply with national legislation and with market access requirements from export countries, and to mitigate reputational risk. Also, international consumers have indicated willingness-to-pay (WTP) for the guaranteed safety of the food products that they buy. In addition, the importance of science for food safety has been codified by national and international agencies (e.g. WHO, FAO, FDA), and is an important strategy priority for the New Zealand Government.

Studies examining the value of food safety science are sparse in the literature. Instead, much of the literature focuses on the impact of food safety policies, programmes or interventions which can include scientific efforts (Chinnici et al., 2014; Crutchfield et al., 1997; Golan et al., 2000; Mazzocchi et al., 2013; McLaughlin, 2007; Tanaka, 2005). These include some cost-benefit analyses (CBA) examining the implementation of food safety control programmes for specific pathogens in specific industries (Gavin et al., 2018; Goldbach and Alban, 2006; Ivanek et al., 2004; Kangas et al., 2007; Maldonado et al., 2005). However, these often do not specifically examine the role of science for food safety. There is an additional stream of literature focusing on the overall costs and/or benefits of maintaining food safety which usually considers this from a technical or methodological perspective rather than an applied approach (Adinolfi et al., 2015; Caswell, 2008; Fritz and Schiefer, 2008; Golan et al., 2000; Krupnick, 2001; Mazzocchi et al., 2013; McLaughlin, 2007; Pitter et al., 2015).

3.1 The role of science in food safety protection

As previously discussed, the WHO (2022b) considers food safety science to be one of five Strategic Priorities within their *Global Strategy For Food Safety 2022-2030*, and a key underpinning aspect of the strengthening of national food control systems. Specifically, food safety science is a key factor in the development of evidence-based regulatory approaches, suggesting that scientific evidence should be used in making risk management decisions. This includes real-time response to food safety outbreaks as well as the development of long-term evidence-based policy and regulatory approaches for food safety. In particular, the WHO outlines the importance of scientific evidence in assessing the presence and intensity of food hazards, as well as the technical feasibility and cost effectiveness of potential control measures (WHO, 2022b).

The Centers for Disease Control and Prevention (CDC, 2018) provide an outline of the seven potential steps involved in detection of foodborne illness outbreaks through to their resolution. Science has a key role in most steps of this process, as outlined below:

Step 1 – Detect Outbreak
The detection of a foodborne illness outbreak requires scientific input. At this stage of the process, a patient that may have consumed an affected food product may present their symptoms to a doctor, during which the doctor may take samples from the patient. This requires sending patient samples to a clinical laboratory to help identify the pathogen involved (e.g. bacteria, virus). Following this, the sample of the pathogen may be sent to a state public health laboratory for DNA fingerprinting. If Whole Genome Sequencing is applied in this step, the outbreak detection is sped up significantly.

Step 2 – Define and Find Cases
This step involves identifying other potential cases with the same pathogen incidence in the general population. This can be achieved by creating a "case definition", which describes the features of the illness, its DNA fingerprint, the pathogen or toxin involved (if known), symptoms associated with the pathogen or toxin, and time and geographic ranges of illness. This stage requires scientific input, particularly in the DNA fingerprinting and other laboratory analysis needed to identify the pathogen involved.

Step 3 – Generate Hypotheses About Likely Sources
This step requires less scientific input, as it mainly concerns carrying out interviews or generating leads as to potential sources of foodborne illness based on the case definition created in the previous step.

Step 4 – Test Hypotheses
This step involves testing the hypotheses generated in the previous step regarding the foodborne illness' origins through a variety of means, including scientific input. Specifically, lab-based testing is used to support hypothesis confirmation through DNA fingerprinting and similar methods in order to triangulate the potential cause of the outbreak.

Step 5 – Solve Outbreak
Once a potential source has been identified, the next step involves linking the collected evidence with the potential source and establishing linkages. Scientific input is critical at this stage, as testing helps to determine the potential source and provides evidence as to its origins.

Step 6 – Control an Outbreak
This step involves the implementation of control measures (such as cleaning food production and processing facilities, closing plants, recalling food products) to control and minimise the risk of the outbreak to the public. While informed by scientific evidence, this stage does not require new scientific knowledge to be carried out.

Step 7 – Decide End of Outbreak
This final step involves the declaration of the end of an outbreak once the epidemiological curve starts to flatten out. This step does not require specific scientific input (CDC, 2018).

The WHO (2022b) outlines the various possible sources of information regarding the source of potential food safety outbreaks:

> *For imported foods, exporting country risk profiles, importer declarations and the results of border and post-border inspection and monitoring should be combined as information sources to continuously evolve towards evidence-based imported food safety systems.*
>
> *For food produced domestically, information sources start at the production level and are strengthened by supplier declarations, traceability arrangements and monitoring during primary and secondary processing* (WHO, 2022b, p.34).

New Zealand's food safety system is complex, comprising a range of specific programmes across multiple agencies. The Ministry for Primary Industries (MPI) is the key body enforcing New Zealand's food safety legislation and regulations, including Agricultural Compounds and Veterinary Medicines Act 1997, Animal Products Act 1999, Food Act 2014, and Wine Act 2003. MPI's food safety role encompasses the following:

- The development, regulation and implementation of food standards;
- The provision of official assurances and certification for wine, animal, and plant food products for exporters to overseas markets;
- and The control of products that can be used in New Zealand agriculture, and response to food safety incidents and suspected breaches of corresponding legislation (MPI, 2022b).

MPI audits and monitors New Zealand's food safety system, including identifying and minimising food safety risks, as well as monitoring food imports for their safety. This approach requires food products to meet specifications of safe limits of chemical residues, contaminants or toxins, which can include agricultural compounds and veterinary medicines. In addition, MPI provides food assurance and verification against food safety standards, including the issuing of certification for food exports (MPI, 2022b). New Zealand's food safety system focuses on three key areas: imported food, domestically produced and consumed food, and exported food.

There are multiple points that require scientific services within New Zealand's food safety system. Firstly, food safety monitoring is required under the Animal Product Act 1999, which includes several specific monitoring programmes – the National Microbiological Database (NMD), the National Chemical Residues Programme (NCRP), the National Chemical Contaminants Programme (NCCP), a range of seafood-based programmes, the Independent Verification Programme (IVP) for dairy products, and risk management control programmes (MPI, 2022c). These programmes require the scientific testing of food products to ensure compliance with New Zealand legislation.

An example of this is the National Microbiological Database (NMD). Under the requirements of the programme, agricultural producers must provide samples of animal products (namely cattle, goats, deer, ratites (e.g. emus and ostriches), sheep, pigs, and poultry) for standardised microbiological sampling and testing for ongoing monitoring for food control. This includes the completion of microbiological testing by a recognised laboratory, the results of which must be reported to MPI (MPI, 2022d). These laboratories must be recognised by MPI in order to comply with the requirements of the Animal Products Regulations 2021 and Animal Products Notice: Recognised Laboratories (MPI, 2022e).

At the same time, food exports may be subject to Overseas Market Access Requirements (OMAR). These are requirements to be met by destination countries for exports from New Zealand. These often require additional scientific testing for food safety to be carried out for specific products into specific markets. For example, all Category A edible by-products of bovine, ovine, and caprine intended for the Chinese market must undergo testing for salmonella as a condition of OMARs (MPI, 2022e). MPI (2022e) maintains a consolidated list of all testing requirements under the NMD for exported primary products. This includes requirements for testing across a range of product types, test types, and countries (including generic requirements under New Zealand law), comprising a total of 934 tests (as of October 2022). These are listed in Table 3-1. In addition, the number of specific tests required by product type and testing type are listed in Table 3-2. This clearly shows the economic importance of food safety science, as this list comprises many of New Zealand's most valuable export commodities (e.g. meat and meat products, dairy products) and trade partners (e.g. China, USA, Japan, Australia).

Table 3-1: Overseas Market Access Requirements (OMAR) – Product Types, Methods, and Countries (as of October 2022).

Product Types	Test Types	Countries
• Blood and blood products • Dairy products • Deer velvet • Egg and egg products • Fish (all seafood) • Gelatine and collagen • Honey and bee products • Infant formula, food for infants, and foods for special medicinal purposes • Live animals and germplasm • Meat and meat products • Pet food and animal feed • Poultry • Tallow, fats and oils • Water • Residue Monitoring Programmes (RMPs)	• Chemistry • Disease and Genetic Tests • Microbiology • Parasitology • Physical	• Australia • Cambodia • Canada • China • Cook Islands • European Union • Eurasian Economic Union • Fiji • Finland • French Polynesia • Hong Kong • India • Indonesia • Iran • Japan • Kiribati • Korea • Mauritius • Nepal • New Caledonia • Niue • Papua New Guinea • Philippines • Samoa • Singapore • Solomon Islands • South Africa • Sweden • Taiwan • Tonga • Tuvalu • USA • Vanuatu • Vietnam • Other countries with the same requirements as Sweden and Finland

Source: Adapted from MPI, (2022f).

Table 3-2: OMARs by Product Type and Testing Type (as of October 2022).

		Test Types					
		Chemistry	Disease and Genetic Tests	Microbiology	Parasitology	Physical	**TOTAL**
Product Type	Blood and blood products			12			**12**
	Dairy products	44		21		9	**74**
	Deer velvet	2					**2**
	Egg and egg products			32			**32**
	Fish (all seafood)	27		35		1	**63**
	Gelatine and collagen	9		4			**13**
	Honey and bee products	4		5			**9**
	Infant formula, food for infants, and food for special medicinal purposes	1		10			**11**
	Live animals and germplasm		143				**143**
	Meat and meat products	86		40	4		**130**
	Pet food and animal feed	1		25			**26**
	Poultry			13			**13**
	Tallow, fats and oils	18		3			**21**
	Water	256		48		12	**316**
	Residue Monitoring Programmes (RMPs)	69					**69**
	TOTAL	**517**	**143**	**248**	**4**	**22**	**934**

Source: Adapted from MPI, (2022f).

3.2 Consumer preferences for food safety

Internationally, there is evidence that consumers value food safety, and are willing to pay a premium for the inclusion of this attribute in the food products that they buy (Guenther et al., 2015; Miller et al., 2017; Saunders et al., 2016; Tait et al., 2016). This is understandable due to widespread public concerns regarding food safety incidents around the world. Overall, results from these studies demonstrate that differences in consumer preferences and their willingness to pay a premium for food safety credentials exist between countries. An extensive literature review on consumer preferences and their willingness to pay for food safety attributes in food products can be found in Appendix A. This draws heavily on Driver et al. (2022).

3.3 The importance of science for food safety

As demonstrated in earlier chapters, science is critically important for the maintenance of a safe food supply. The importance of food safety science has been highlighted by major international agencies, including the FAO and WHO.

WHO chief scientists have stated *"…it is important to understand the nature and level of hazards in the food chain because your interventions to ensure food safety depend on understanding, which will have the most impact in reducing the risk"*. In particular, FAO and WHO chief scientists have indicated that techniques such as whole genome sequencing (WGS) should be used more prominently by countries for food safety monitoring and outbreak management, with WHO chief scientist Soumya Swaminathn stating *"…we need to invest in laboratory science, training bioinformatics experts and molecular biology."* Similarly, the FAO's chief scientist stated *"…whole genome sequencing allows us to understand better in epidemiological surveillance, food testing, monitoring and outbreak investigation but we need to do more"* (Whitworth, 2021).

The WHO (2022b) have further recommended the synthesis and coordination of scientific guidance for food safety to effectively implement the Global Strategy for Food Safety 2022-2030. Specifically, the WHO recommends that scientific evidence is codified and incorporated into international food safety standards (WHO, 2022b). Similarly, the FAO have stated in a 2022 report examining the future of food safety that *"it is worthwhile to iterate that science is central to food safety. Development and application of sound scientific principles underpin the formulation of appropriate food safety regulatory frameworks and policies that are needed to safeguard public health amid ever-changing agrifood systems"* (FAO, 2022b).

The importance of science for food safety policy has also been outlined by the US Food and Drug Administration (FDA). The FDA has stated that "*good science is critical to regulatory decision-making*", illustrating this importance across a number of areas. According to Henney (2001), in the US, science has specifically:

- Enabled the development of new technologies for the detection of new and evolving foodborne health hazards, such as virological techniques for detecting and fighting foodborne illnesses such as Hepatitis A;
- Enabled the development of solutions for public health problems. For example, with reference to the safety of sprouts, science has assisted in the development of evaluation methods for a range of potential agents as a means of decontaminating seeds and sprouts, and Good Agricultural Practices for fresh fruit and vegetables (applied internationally);
- Contributed to new regulatory approaches to Hazard Analysis Critical Control Point (HACCP) enforcements, such as the issuing of science-based mandatory HACCP for seafood products;
- Enabled the development of new means of measuring public health impacts of prevention and control.

The importance of food safety science has also been highlighted through examples of scientific intervention in food safety incidents. Considering the significant social, economic and other costs that foodborne illness can cause (see Chapter 2). Many of these can be prevented or effectively mitigated through the implementation of scientific techniques to determine the causes of food safety outbreaks, and to mitigate further negative impacts.

In New Zealand, the maintenance of a safe food supply is a key objective of government policy. MPI is the governing body responsible for overseeing New Zealand's food safety science programme. This is a project-based programme that *"helps to assure safe food for New Zealanders and consumers in export markets"* and *"aims to minimise foodborne illness in New Zealand". This suggests a two-fold approach – safeguarding health (mitigating social cost) and protecting consumers (mitigating economic cost), with science efforts including both imported and New Zealand-produced food. Research is prioritised according to risk, with considerations including "public health priorities, MPI strategy, international market access* issues, and the appropriate and effective use of funds" (MPI, 2022a).

An example of the importance of food safety science in New Zealand was shown in Fonterra's WPC80 incident (outlined in detail in Section 2.3). While initial impacts were clearly substantial, Fonterra commissioned an independent 'Government Inquiry into the Whey Protein Concentrate Contamination Incident' (2014). The inquiry included substantial scientific testing of isolated samples of suspected products. Some tests found that bacteria in products were more consistent with C. botulinum than with a similar but relatively harmless and more common bacterium C. sporogenes. Fonterra then intensified traceability looking at the destinations of affected products to prevent further harm (Hodder et al., 2013). Finally, later testing showed that the bacterium was C. sporogenes rather than C. botulinum, hence averting a health crisis and allowing Fonterra to initiate reputational damage repair (Tajitsu, 28 Aug 2013). This incident shows the high importance of food safety science. It resulted in Fonterra employing the technology of whole genome sequencing to allow accurate identification of pathogens in processing. Further, the independent inquiry of the WPC80 event let to recommendations of the establishment of a collaboration between research centres and the food sector such as the NZFSSRC (Government Inquiry into the Whey Protein Concentrate Contamination Incident, 2014).

Chapter 4
Conclusion

Food safety is critically important to human and animal health, as well as to society and economy. In New Zealand, the maintenance of safe food supply, including response to acute food safety incidents is written into government policy and legislation.

Science plays a central role in food safety control and is often key in determining the source and extent of food safety incidents leading to effective management and control of pathogens. In particular, scientific testing of food products has been shown important to international agencies and national governments in preventing damages from unsafe food. In New Zealand, the New Zealand Food Safety Science and Research Centre (NZFSSRC) was established at Massey University in Palmerston North in 2016. The Centre joins with eight science research partners to form a virtual research centre network. It synthesises input from industry, government, researchers and Māori to promote, coordinate and deliver food safety science and research for the country. NZFSSRC is funded by both the government and industry. The Centre's role in underpinning New Zealand's reputation for safe food is vitally important.

There are significant costs associated with unsafe food, both nationally and internationally. An estimated 600 million people (almost one in 10 people globally) fall ill after eating contaminated food, resulting in a global annual burden of approximately 33 million disability-adjusted life years (DALYs) and 420,000 premature deaths. In addition, low- and middle-income countries are disproportionately affected relative to high-income countries, with an annual estimated cost of US$110 billion in productivity losses, trade-related losses and medical treatment costs due to the consumption of unsafe food.

The importance of producing safe food, as well as the economic and social costs of not doing so, are well understood, but can be difficult to accurately quantify. Many studies have estimated the total costs from food safety incidents, showing significant costs to both the public and private sectors. This includes social costs, including mortality, illness, disability, reduced quality of life, as well as public costs, such as the cost of hospitalisation or productivity loss. Economic costs include firm level costs (e.g. costs related to food recalls, traceability), as well as wider costs for the industry or economy as a whole (e.g. trade disruptions, compliance costs and prolonged reputational damage). These costs vary depending on many factors, including the type of pathogen involved, the region affected, the breadth and severity of the incident, as well as the company's and industry's response.

Studies across a wide range of food safety incidents – nationally and globally - were included in this review to outline the many impacts from food safety outbreaks. It is important to point out that the estimates of these studies may be underestimates of the actual costs of foodborne incidents, given their complexity, data availability and/or difficulties in measuring all impacts. Also, the literature highlights that the actual number of people affected by food safety incidents might be significantly higher than those reported. Further, care should be taken when considering overseas studies for estimating the potential costs of food safety outbreaks in New Zealand. Costs from outbreaks in other countries can vary significantly from those in New Zealand.

There a many benefits of maintaining a safe food supply and mitigating food safety incidents. In addition to preventing associated costs from a food safety outbreak, consumers in international markets (including key markets for New Zealand's food exports) prefer safe food products and are willing to pay a premium for the inclusion of food safety credentials in the products that they buy. The premiums that consumers are willing to pay for food safety attributes are among the highest for any other food product attribute.

This presents a potential market opportunity to producers, processors and exporters in New Zealand to increase value for their products in order to offset the cost of food safety process enhancement.

The next stage of this project includes an economic valuation of food safety science in New Zealand. In particular, it will examine the economic benefits of the New Zealand Food Safety Science and Research Centre (NZFSSRC) to the New Zealand food industry and the economy as a whole.

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Appendix A
Consumer Preferences and their Willingness-To-Pay for Food Safety Credentials in Food Products

This Appendix presents a literature review on consumer preferences and their willingness to pay (WTP) for food safety credentials in food products. The review draws heavily on Driver et al. (2022).

A wide range of studies worldwide have investigated consumer attitudes and preferences for different attributes in food products. In their study, Guenther et al. (2015) examined consumer preferences in China, India, Indonesia, Japan and the United Kingdom (UK) towards several attributes in food products. Initially, ten attributes were selected (*quality, price, animal health, animal welfare, environmental condition, health enhancing foods, food safety, social responsibility, nutritional value, and traditional cultures*) with participants in each country indicating the importance of each attribute when shopping for food and beverages. Of all ten attributes, *food safety* in food and beverages was rated most important across all countries, followed by *quality*, then *nutritional value* (Guenther et al., RR 2015). From the ten attributes, six key ones were selected for more detailed analysis with *food safety* being one of them. For each of these attributes, participants were asked to rate the importance of a set of factors underpinning each key attribute in the supply chain. For food safety, participants across all countries rated *freshness, hygiene standards* and *labelling of "use by date*" as the most important factors associated with this attribute. Cross-country comparisons showed that Chinese participants rated *hygiene standards* as the most important factor underpinning food safety while Indian and Indonesian participants indicated the labelling of a product's *"use by date*" to be the most important factor. For Japanese and UK participants, *freshness* was the most important factor underpinning food safety. *Animal welfare* underpinning food safety was the least important factor across all countries, except for the UK where *GM-free food* was the least important factor related to food safety (Guenther et al., 2015).

In earlier work of the AERU, Saunders et al. (2013) showed that food safety was the most important attribute when assessing consumers' willingness to pay (WTP) and preferences for the certification of certain attributes in lamb and dairy products in UK, China and India. Not surprisingly, India and China rated food safety certification as more important than respondents from the UK (Saunders et al. 2013).

For China, studies have shown that food safety is the most important attribute for consumers (Saunders et al., 2013; Guenther et al, 2015; Zheng et al., 2013; Lai et al. 2018; Yang & Fang 2020). Chinese consumers' confidence in food safety has been a challenge and concerns for food safety may have increased since food safety incidents occurred – nationally and internationally (Lai et al., 2018) – such as the Fonterra WPC80 incident in 2013, Avian Influenza (Bird flu) in 2010, or the 2008 melamine scare in infant formula.

For Japan, several studies have assessed consumers' attitudes towards credence attributes in food. Food safety is very important for Japanese consumers, in their study (Yang et al., 2021) showed that food safety was the most important attribute for Japanese consumers in imported fruits and vegetables, followed by freshness. Also, Haydon et al. (2013) showed that Japanese consumers perceived locally-produced pork safer than imported pork. Kim (2008) found a food product's country of origin was a key determinant in consumer perception of food risk in Japan.

Similarly, food safety is an important attribute in food for UK consumers (Eurobarometer 2019; Guenther et al., 2015; Saunders et al., 2013), and this has grown in importance after food safety scares such as the 2013 Horsemeat adulteration scandal and the 2011 German sprouts *E. coli* outbreak (EFSA, 2012).

Yang & Renwick (2019) conducted a meta-analysis of several attributes for livestock products, including food safety. The authors conducted a systematic literature review and applied a meta-regression analysis in an effort to introduce some generality to WTP studies. A total of 566 WTP estimates from 94 studies were initially identified. For dairy products, food safety was associated with the highest price premiums, with an average consumers' WTP of 39 per cent more than the usual price for dairy products with food safety attribute. For red meat, the average consumers' WTP was 22 per cent per cent more than the usual price for red meat products with food safety attribute (Yang & Renwick, 2019).

Viegas et al. (2014) examined Portuguese consumers' WTP for food safety, alongside environmental quality and animal welfare, in beef products to determine whether premiums could justify increased production costs. Estimated WTP values showed that consumers were willing to pay the highest premium for the provision of food safety credentials, ranging between 7-16 Euros per kilogram, followed by animal welfare and environmental protection. The authors then examined consumers' WTP for attributes in relation to each other, showing that WTP for food safety in the presence of both animal welfare and environmental certification decreased the average WTP (from up to 16 Euros to negative or close to zero). This suggests that, in this instance, consumers may consider the attributes animal welfare and environmental condition to be proxies for food safety (Viegas et al., 2014).

Byrd et al. (2017) examined US consumers' WTP for a range of attributes associated with chicken breast and pork chop products, including antibiotic use alongside other attributes (such as local production and animal welfare) by certification body (USDA, retailer, industry). This showed that consumers were willing to pay the highest premiums for the provision of certified credentials relating to antibiotic use relative to the other attributes (pasture access, local production, and individual crates (in the case of pork)) for both chicken breast and pork chop products. For chicken breast products, consumers were willing to pay the highest premium for USDA-certified antibiotic use credentials (US$1.87 per pound, 75 per cent positive WTP), followed by retailer- (US$1.33 per pound, 74.3 per cent positive WTP) and industry-certified products (US$1.11, 61.7 per cent positive WTP). Similarly, for pork chops, consumers were willing to pay the highest premium for USDA-certified antibiotic use credentials (US$4.55 per pound, 85.7 per cent positive WTP), followed by retailer- (US$1.32 per pound, 61.7 per cent positive WTP), and industry-certified products (US$1.17 per pound, 70 per cent positive WTP) (Byrd et al., 2017).

Ortega et al. (2014) examined US consumer WTP for a range of attributes of shrimp and tilapia products, including enhanced food safety, no antibiotic use and eco-friendly production processes, from a range of different COO. As shown in Table A1, for shrimp products, consumers were willing to pay the highest premium for enhanced food safety (US$10.65 per pound (118 per cent premium) from USA, US$3.71 per pound (41 per cent premium) from China, and US$4.12 per pound (46 per cent premium) from Thailand). Similarly, as shown in Table A2, for imported tilapia in general, consumers indicated the highest WTP for enhanced food safety (US$6.02 per pound (120 per cent premium) for US government verified imported tilapia, US$4.43 per pound (89 per cent premium) for US third-party verified imported tilapia) relative to the other attributes (Ortega et al., 2014).

Table A1: WTP for shrimp attributes by country-of-origin (USA).

	Country of origin	WTP (US$/lb)	Premium (%)
Enhanced food safety	USA	10.65	118
	China	3.71	41
	Thailand	4.12	46
Antibiotic use not permitted	USA	9.83	109
	Thailand	2.84	32
Eco-friendly production practices	USA	5.40	60

Source: Ortega et al. (2014).

Table A2 WTP for shrimp attributes by country-of-origin (USA).

	Country of origin	WTP (US$/lb)	Premium (%)
Enhanced food safety	USA	10.6	118
	China	3.71	41
	Thailand	4.12	46
Antibiotic use not permitted	USA	9.83	109
	Thailand	2.84	32
Eco-friendly production practices	USA	5.40	60

Source: Ortega et al. (2014).

Lai et al. (2018) examined Chinese consumers' WTP for a range of attributes of pork products, including food safety alongside animal welfare, environmental standards and COO, in Beijing and Shanghai. As shown in Table A3, consumers in both cities were willing to pay the highest premiums for food safety relative to the other attributes. Specifically, Beijing consumers were willing to pay a premium of 32.01 RMB, while Shanghai consumers were willing to pay a premium of 32.32 RMB for this attribute (Lai et al., 2018).

Table A3: WTP for pork product certification attributes, China (Beijing and Shanghai).

	Mean WTP (RMB)	
	Beijing	Shanghai
Food Safety	32.01	32.32
Animal Welfare	7.65	13.11
Environmental Standards	11.81	20.73
Country of Origin: USA	4.31	9.61
Country of Origin: China	13.26	30.11

Source: Lai et al. (2018).

Wang et al. (2018) estimated Chinese consumer WTP for pork products with certified attributes, including food safety and free from veterinary drug residues, alongside green food, organic food, and location of origin, in two Chinese provinces (Jiangsu and Anhui). As shown in Table A4, while specific food safety certification had the lowest associated premium (8.10 Yuan per 550g product in Jiangsu, 7.21 Yuan per 550g product in Anhui), the attribute *free from veterinary drug residues* had the highest associated premium (23.18 Yuan per 550g product in Jiangsu, 15.40 Yuan per 550g product in Anhui) (Wang et al., 2018).

Table A4: WTP for pork product certification attributes, China (Jiangsu and Anhui provinces).

	Mean WTP (Yuan per 550g product)	
	Jiangsu	**Anhui**
Safe Food	8.10	7.21
Green Food	20.22	17.63
Organic Food	26.78	18.94
Location of Origin shown	12.77	10.99
Free from veterinary drug residues	23.18	15.40

Source: Wang et al. (2018).

Ortega et al. (2015) examined Chinese consumer WTP for pork, chicken and egg product attributes, including food safety alongside animal welfare, organic certification and green food claims, in a range of food retail contexts (wet market, domestic supermarket, and international supermarket). As shown in Table A5, the highest premiums for all product types were associated with enhanced food safety claims, with premiums varying depending on retailer type. For example, for pork products, consumers were willing to pay the highest premium for food safety from wet markets (27.73 RMB per product, or 213 per cent premium), followed by international supermarkets (25.50 RMB per product, or 196 per cent premium) and domestic supermarkets (23.68 RMB per product, or 182 per cent premium) (Ortega et al., 2015).

Table A5: WTP for pork, chicken and eggs product certification attributes, China.

Product Claim	**Retailer Type**	**WTP RMB/product (premium %)**		
		Pork	***Chicken***	***Eggs***
Enhanced food safety	Wet market	27.73 (213%)	19.94 (199%)	9.93 (199%)
	Domestic supermarket	23.68 (182%)	26.69 (267%)	9.58 (192%)
	International supermarket	25.50 (196%	21.45 (215%)	8.23 (165%)
Animal welfare	Wet market	-	-	-
	Domestic supermarket	7.36 (57%)	-	-
	International supermarket	-	-	2.28 (46%)
Organic certification	Wet market	-	-	3.28 (66%)
	Domestic supermarket	11.48 (88%)	15.44 (154%)	5.37 (107%)
	International supermarket	12.11 (93%)	-	3.89 (78%)
Green food	Wet market	-	-	5.07 (191%)
	Domestic supermarket	11.79 (91%)	19.69 (197%)	6.76 (135%)
	International supermarket	19.29 (148%)	16.27 (163%)	6.63 (133%)

Source: Ortega et al. (2015).

Tait et al. (2016) conducted a cross-country analysis (China, India and the United Kingdom (UK)) of WTP for a range of lamb attributes, including food safety alongside farm animal welfare, water management, Greenhouse Gas (GHG) minimisation, biodiversity enhancement, and country of origin. As shown in Table A6, food safety was associated with the highest overall premium by Chinese and Indian participants, and second-highest for UK participants. Specifically, Indian participants valued the attribute the highest (49 per cent premium), followed by Chinese (34 per cent premium) and UK participants (15 per cent premium) (Tait et al., 2016).

Table A6 WTP for lamb product certification attributes – China, India and the UK.

	WTP (% of product price)		
	China	***India***	***UK***
Food safety	34	49	15
Farm animal welfare	9	29	18
Water management	7	21	6
Greenhouse Gas (GHG) minimisation	8	28	6
Biodiversity enhancement	5	16	4
COO: Domestic	-27	-	5
COO: Foreign	-	13	-5

Source: Tait et al. (2016).

Wu et al. (2014) examined Chinese consumers' WTP for organic infant formula attributes based on participants' level of knowledge of, and level of perceived risk associated with such products across a range of COO. Results are summarised in Table A7, showing that those with both higher levels of product knowledge and greater perceptions of risk were generally more likely to pay for organic infant formula products. This suggests a possible perceived association between organic production and greater food product safety (Wu et al., 2014).

Table A7: WTP for organic infant formula by country of origin, level of knowledge, and level of risk perception, China.

	WTP US$/400g (Premium %)			
Country of Origin	***Full Sample***		***By level of knowledge***	***By level of risk perception***
China	3.23 (22%)	Low	3.49 (23%)	3.84 (26%)
		Medium	3.84 (26%)	4.28 (29%)
		High	1.95 (13%)	4.20 (28%)
European Union	5.36 (36%)	Low	3.81 (25%)	3.75 (25%)
		Medium	6.93 (46%)	6.02 (40%)
		High	6.04 (40%)	6.25 (42%)
USA	10.40 (69%)	Low	10.66 (71%)	9.93 (66%)
		Medium	16.87 (112%)	12.58 (84%)
		High	16.55 (110%)	12.89 (86%)

Source: Wu et al. (2014).

Tait et al. (2018) explored Chinese consumers' WTP for New Zealand yogurt product attributes, including enhanced food safety alongside enhanced animal welfare, organic production, environmentally sustainable, social responsibility, and a range of COO (China, Germany, Spain, Thailand, and New Zealand). Results are presented in Table A8, showing a WTP of 44 RMB, or a 54 per cent price premium, for enhanced food safety.

Table A8: Shanghai consumer WTP for selected yogurt product attributes.

Attribute	WTP ¥/kg (Premium %)
Enhanced food safety	¥44 (54%)
Enhanced animal welfare	¥37 (45%)
Environmentally sustainable	¥39 (47%)
Social responsibility	¥31 (38%)
Organic	¥42 (51%)
COO: China	¥77 (93%)
COO: Germany	¥70 (85%)
COO: Spain	¥48 (58%)
COO: Thailand	¥-9 (-11%)
COO: New Zealand	¥118 (143%)

Source: Tait et al. (2018).

Taken as a whole, the literature shows a clear preference among consumers in a range of international contexts for the provision of safe food products, including a willingness to pay a premium for such products. This preference has been shown to be the strongest across all other attributes, with consumer WTP for food safety credentials most often the highest compared with other food product attributes examined. This not only indicates clear consumer preferences for verified or enhanced food safety, but also a potential market opportunity to producers and processors to increase value for products in order to offset the cost of food safety process enhancement.