Drivers of existing and emerging food safety risks: Expert opinion regarding multiple impacts

Helen Kendall [1], Gulbanu Kaptan [1, 2], Gavin Stewart [1], Matt Grainger[1], Sharron Kuznesof [1*], Paul Naughton [1], Carmen Hubbard [1], Marian Raley [1], Hans Marvin [3], and Lynn J. Frewer[1]

[1] School of Agriculture, Food and Rural Development, Newcastle University, Newcastle Upon Tyne, NE1 7RU, UK

[2] Centre for Decision Research, Leeds University Business School, Maurice Keyworth Building, GM.30, Leeds, LS6 1AN, UK

[3] RIKILT -Wageningen UR, Akkermaalsbos 2, 6708 PD, Wageningen, The Netherlands

***Author to whome correspondence should be addressed:**
Sharron.Kuznesof@newcastle.ac.uk

Acknowledgements

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement nº 311611. This paper reflects only the authors' views and the European Union is not responsible for any use that might be made of the content of the information contained in it. We would like to thank the European Commission for funding this research.

Abstract

Considerable research effort is invested in the development of evidence to help policy makers and industry deal with the challenges associated with existing and emerging food safety threats. This research aimed to elicit expert views regarding the relationship between the drivers of existing and emerging food safety risks, in order to facilitate their control and mitigation, and to provide the basis for further international policy integration. A Delphi approach involving repeated polling of n=106 global food safety experts was adopted. The primary drivers of existing and emerging food safety risks were identified to be *demographic change, economic driving forces, resource shortages, environmental driving forces, increased complexity of the food supply chain, water security and malevolent activities*. The identification of socio-economic and biophysical drivers emphasises the need for a transdisciplinary and systems approach to food safety management and mitigation. The mitigation of hazards on a case-by-case basis is unlikely to have a major impact on food safety hazards but may have unintended effects (where positive or negative) across a broad spectrum of food safety issues. Rather a holistic or systems approach is required which can address both the intended and unintended effects of different drivers and their interactions.

Key words: food safety; emerging risk; existing risk; Delphi technique; expert opinion

1. Introduction

Food-borne risks represent a serious threat globally (FAO, 2006) and have negative impacts in all countries and regions (Ercsey-Ravasz *et al*, 2012; Johnson *et al*, 2012; Prakash, 2014; Wu and Chen, 2013). Despite attempts to manage food safety, food borne illness has considerable negative impacts on public health (Havelaar et al, 2010). Food safety has been recognised by many national governments as a major social cost, threatening consumer health, producing inefficiencies in animal and plant production systems, and creating trade barriers across the global food web. Substantial resources have been invested in national and regional initiatives (including those focusing on research, scientific training programmes, and enactment of regulation to protect the environment and human health), which aim to improve international food safety standards. However, external drivers of food safety, which originate in the social and natural domains, mean that new food risks continue to emerge (van de Brug *et al*, 2014; Sundström *et al*, 2014; Smith *et al*; 2014). Hence, the aim of this research is to identify and map the views of international experts regarding the knowledge gaps associated with the drivers of existing and emerging food risks, as well as understand the potential barriers to risk identification and management. Emerging food risk identification, prevention and mitigation will, at the global level, require harmonisation of existing evidence regarding what is, and what is not, known about emerging risks worldwide, as well as the need to integrate different methodological approaches in single predictive models to ensure transparent and proactive assessment of these risks.

Emerging food risk is defined as an unanticipated risk that occurs accidently or naturally, as well as arising from deliberate fraud or acts of malevolence (Kennedy, 2012; Marvin *et al*, 2009; Spink and Moyer, 2011; Schwägele, 2005). The extent to which an emerging food risk affects the health of citizens and animals, and the environment, or has economic or social impacts, may depend upon a country or region's level of development,

internal regulatory system, infra-structure, and capacity relating to identification and mitigation strategies. The impact of such risks may also negatively affect the (regional, national and international) economy and have social consequences (for example, on employment). Direct economic costs include those risks attributable to health care and time lost from employment, plus costs incurred by industry as a consequence of food recalls (Oken *et al*, 2012). Indirect costs may include loss of consumer confidence in types of food product or specific brands, resulting in lost sales (Jensen and Jensen, 2013; Pennings *et al*, 2002).

Emerging food risks are not necessarily new risks. Some have only recently been identified due to improved detection techniques (Skovgaard, 2007), while others are the result of mutations and adaptations of well-known microorganisms. In some cases, risks emerge as an unintended side effect of a deliberate control measure (Li *et al*, 2015; Ladics *et al*, 2015). Other risks may emerge in specific regions due to changes in external conditions. For example, climate change may introduce tropical food safety hazards in regions with a (previously) moderate climate (Zhang *et al*, 2008). Global food risk management can only be as effective as local food risk management, which in turn will depend on the effectiveness of localised regulation (and the extent to which these regulations are enforced locally), socio-cultural factors (e.g linked to local cooking practices), and the immediate environment. Local factors may determine whether a food risk emerges in the first place, and whether it can be identified, managed and, if necessary, mitigated.

Regional differences in the application of safety standards may compromise international trade and, as a consequence, have a negative impact on food security (Lee *et al*, 2012). In this context, the increasing complexity of the food supply (often at the global level) has sometimes resulted in the more rapid national and international spread and impact of food safety problems, which indicates the urgent need for knowledge exchange at the regional, national and international levels across stakeholder groups (Marucheck *et al*, 2011). Various

potential drivers of existing and emerging food safety risks can also be identified, indicating that food safety policies must address drivers and their consequences originating in both the natural and social domains.

Given that drivers of food safety risks, such as climate change, fraud, unintended effects of implementation policies, perceived risks of new technologies (e.g. biotechnology and nanotechnology), and demographic developments are experienced around the world (albeit with potentially different health, environmental and economic impacts), it is important to acknowledge that policy responses must also include elements which are rooted in different levels of knowledge, cultural traditions and practices, and socio-historical contexts, all of which are also subject to temporal change and influence by external events (Bielenia-Grakewska, 2015; Frewer *et al*, 2016; Jacobs *et al*, 2015; Loebe *et al*, 2011).

Globally, research programmes generate a huge amount of data that could help policy makers and industry deal successfully with the challenges associated with food safety (Crandall *et al*, 2012; Feskens *et al*, 2011; Havelaar *et* al, 2013; Jespersen and Halberg, 2012; Jia and Jukes, 2013; Percy, 2011; USDA, 2015). Thus, at the international level, cooperation on food safety and the sharing of food safety knowledge may lead to more efficient use of research funds, the sharing of best practices, the development of effective risk mitigation strategies and food risk policies (Käferstein and Abdussalam, 1999; Wentholt *et al*, 2010), and durable partnerships between international food trading partners (Meunier and Nicolaidis, 2006).

In order to explore the views of international experts regarding the knowledge gaps associated with the drivers of existing and emerging food risks and the potential barriers to risk identification and mitigation, the following research questions were developed:

1. What are the drivers of existing and emerging food safety risks according to experts?

2. Do experts consider some drivers of existing or emerging food safety risks to be more important in some regions of the world?
3. Do drivers have a positive or negative impact on the occurrence food safety risks?
4. Are barriers to effective food risk identification and mitigation identifiable? Do these differ for existing and emerging food risks?
5. How might identified barriers be addressed in policy?

2. Methods

Eliciting the opinions of international food safety experts required a method that permitted consultation with geographically dispersed participants. The Delphi methodology is a convenient and economical facilitative mechanism that permits interaction and dialogue between experts that are located in different regions of the world (Stow *et* al, 2015; Wentholt *et al,* 2010). It combines the interactivity of group meetings and the practicality of survey methods. Typically, Delphi methodology involves iterated questionnaires being presented anonymously to experts, with controlled feedback between rounds, and the equal weighting of final round responses to produce a group judgement (Linstone and Turoff, 1975). Variations of the method exist, in terms of the number of rounds used, whether or not the first round is structured (quantitative) or unstructured (qualitative), whether the process takes place using paper-and-pencil questionnaires or 'online' data collection methods,whether the process is synchronous or asynchronous. These variations have been reported to have been applied in the literature (e.g. Gordon and Pease, 2006; Rowe et al, 1991). The aims of the approach may vary, that is, Delphi may be conducted in order to gain expert consensus or, importantly, identify dissensus where this exists (e.g. see Turoff, 1970). Typically, Delphi surveys have at least two rounds, whereby participant responses from the first round are fed back to respondents with the aim of providing feedback on the views of other experts regarding the issue at hand. Delphi methodology has successfully been applied to a range of

issues in the food safety domain (Frewer et al, 2011; Kim et al, 2013; More et al, 2010; Soon et al, 2012; Strohbehn et al, 2004; Wentholt et al, 2010; Wentholt et al, 2012). The utility of the method to issues associated with agricultural and food safety policy has therefore been established.

In accordance with the practical recommendations given by Frewer *et al*., (2011) an exploratory workshop was held in Brussels on March 5th, 2013 at the Northern Ireland Executive Offices. Thirty-eight experts from EU member states were invited *via* email to participate in the scoping workshop. Experts were identified through the personal networks of the EU-FP7 Collab4safety project consortium members'[1].

The workshop was attended by 29 experts including, 15 external food safety experts, representing organisations including the FAO, the European Food Safety Authority and food industry, and 14 researchers/academics from eight countries (i.e. Brazil, Ireland, France, The Nertherlands, Poland, Portugal, Russia and the UK)[2] . The use of a preliminary workshop provides opportunity for interactive discussions to shape the Delphi survey itself, and represents a slight hybridisation of classical Delphi methodology (Landeta, et al, 2011). The workshop (as a preliminary stage of a Delphi exercise) aimed to identify and refine key issues to be included within the first round of the Delphi survey. Following a plenary session, where the objectives of the workshop were presented, the participants were assigned to 1of 3 groups. Each group had a moderator, observer and a rapporteur drawn from consortium members, and discussed different topics for 2 hours in total during a moderated discussion. Each group was given a different set of 3 drivers (i.e., demographic change, economic driving forces, environmental driving forces, technological driving forces, geopolitical driving forces, societal values, consumer priorities, malevolent activities, and increased complexity and size

[1] Collab4safety is an EU-FP7 funded project. For more information about Collab4Safety see http://collab4safetyfoodsafetyportal.eu/index.php/home/index/en..

[2] These countries represent the project partners of the Collab4Safety project.

of the supply chain) that had been identified prior to the workshop by the consortium partners of the EU-FP7 Collab4Safety project. The participants in each group were asked to list existing threats to food safety, emerging risks to food safety, research needs, training needs, evidence needed for policy development, and national and international policy gaps in relation to each driver. They were also asked to identify one important driver of emerging food risks and list the above regarding this particular driver. As a result, 3 new drivers (i.e., food risk representation in the media, water security, and political will) were suggested by the groups. Resource shortages that was previously included in environmental driving forces was suggested as a separate driver, making 13 drivers in total that were included in the first round Delphi survey. The key results from the workshop are summarised in Table 1, which is presented with additional supporting literature (Kaptan *et* al, 2013).

TABLE 1 HERE

The outputs of the workshop were used to inform the design of the first round of the Delphi survey, together with findings from a comprehensive literature review. Following a pilot survey, the questionnaire was adjusted, translated into six languages (i.e. French, Portuguese, Spanish, Polish, Chinese and Russian) and then back-translated into English to ensure meaning was retained in the translations. The first round survey was predominantly comprised of closed response questions, although each question was followed by an open response option to allow experts the opportunity to support their answers or indeed provide futher issues for consideration. The survey questions focused on eliciting expert opinion regarding the primary drivers of existing and emerging food safety risks, identified as an outcome of the scoping workshop (see Table 1) and the direction (i.e. an increase or decrease) of these drivers on food safety risks. Prioritisation of both exisiting and emerging food safety risks, which had been suggested by the literature, Collab4safety partners, and workshop participants in relation to the drivers was explored in terms of importance at the

national and global level. The research and policy gaps relevant to the effective identification and mitigation of existing and emerging food safety risks included in the Delphi survey were also identified as a result of the literature review, consultancy with Collab4Safety project partners, and output of the group discussions at the workshop. Experts were asked to consider these at the the national and global level. Additionally, background information about the experts participating in the survey (i.e. gender, age group, country of work, type of organization, area of expertise and job experience) was also collected.

A second round survey sought to build on the findings of the first round. Round 2 aimed to quantify differences in opinion identified in round 1 and establish directions for the future. Kher *et al.*, (2010) advocates that 50% agreement can be taken as the threshold for consensus. In general, a high rate of expert consensus was found in the first round and agreement in this study was therefore taken as >60%. However, the analysis of the round 1 survey showed that there was 'no overall' agreement that the following drivers, *technological changes, geopolitical driving forces, societal values, consumer priorities, political will, and food risk representation in the media,* would increase or decrease existing or emerging food safety risks. This was fed back to participants in the round 2 survey.

Overall agreement that the drivers *demographic change*, *economic driving forces*, *resource shortages*, *environmental driving forces*, *increased complexity and size of the supply chain, water security, and malevolent activities*, increase or decrease existing and emerging food safety risks was found. The result was also fed back to the participants of the round 2 survey. Subsequently questions relating to food safety risks and research and policy gaps were asked to round 2 participants,were asked only in relation to these drivers. In addition, some questions included in the round 1 survey were further explored in round 2 because of polarity in responses. For example, in relation to the barriers to effective identification and mitigation of food risks, 47% agreed that, in their country, there are few skilled professionals working in

the area of food safety. Thus, round 2 survey participants were fed back information about this result and asked about training and capacity building needs in their own countries.

Feedback from the first round was provided to expert participants, and a mixture of closed and open response questions permitted experts to elaborate on their reponses. Given the high rate of consensus obtained in the first round, the second round contained fewer survey questions than the first. Table 2 provides a complete description of the questions asked in both rounds of the Delphi and a full version of both surveys are available from the authors on request.

INSERT TABLE TWO HERE

2.1 Sampling

Based on selection criteria (e.g. geographical location and sectorial representation) n=504 experts were selected from a stakeholder database (n=1,257) created within the Collab4Safety project, and were invited to participate in the first round of the online Delphi survey. Data for the first round survey were collected between December 2013 and January 2014. To increase international participant response rates, participants were offered the opportunity to complete the survey in any one of eight languages (English, Dutch, Chinese, Spanish, Portuguese, French, Polish and Russian). To encourage participation, follow-up emails were sent to participants that had not responded at the mid-point of the survey launch, a week prior to the survey closing, the day before the survey closed, as well as a week after the survey had closed. A total n=106 completed questionnaires were collected in round one. The second round was conducted between October and November 2014. An email invitation was sent to all respondents (n=106) from round one including anonymised feedback on issues where consensus had not occurred in the first round. Again, the second round survey was translated and available in same eight languages as round 1. The same follow up procedures

established in round 1 were followed in round 2. A total of n=42 responses to the second round survey were collected achieving a 40.5% response rate.

2.2 Data Analysis

Analysis was conducted in response to the questions framing the reseach. To address research question 1, descriptive statatistics were used to identify areas of consensus in terms of agreement and disagreement and the polarisation of views. 'Reasonable consensus' in this case was regarded as more than 60%. Second, analysis of variance (ANOVA) was performed using the LM function in R package 3.2.1 to identify statistically significant drivers of existing and emerging risk, and to explore whether there was a significant difference between the expert ratings of importance regarding the drivers of existing, compared to emerging, food safety risks. As the response variable was categorical, multinomial regression using the nnet package (Venables and Ripley, ~~(~~2002), in the R programme (R Core Team, 2016), was used to identify significant interactions between drivers of existing and emerging food safety risk and the following variables; expert's geographical region, level of expertise, gender and age. The global model included all interactions. AIC (Akaike's Information Criterion) to select the most parsimonious models (ΔAIC <2), and model averaging using the MuMIN package (Barton, 2016) was used. -In response to research question 2, anaylsis of variance (ANOVA) was performed to explore whether there was significant differences in the impact of some drivers of existing and emerging food safety risks in different parts of the world. To explore the impact (positive or negative) on the occurance of food safety risks (research question 3), graphs were produced using 'ggplot2' (Wickham, 2009) in R, to map the extent to which experts considered drivers to be increasing or decreasing food safety risks, against the geographical region in which the expert was working. Finally, barriers to the effective idetification and mitigation of food safety risks and gaps in current food safety reseach (resarch questions 4 and 5) were ranked

using mean response, with low mean response scores (i.e. mean value close to 1=agree) and low variation across the sample indicated by Z-score.

3. Results

3.1 Sample

A final sample of 106 responses was achieved in round 1 (21% response rate). In round 2, 42 participants completed the questionnaire (40.5% response rate) (see Table 3). A reduction in response between rounds is typical within Delphi surveys, and in this case there was a 60% reduction in response between the first and second round surveys. Wentholt et al (2010) report a 27% response rate between the first and second rounds of a Delphi survey applied to food safety issues. The time which elapsed between the first and second rounds may provide a possible explanation for the higher than average rates of attrition in the current study. Using the criteria of age (57% of the total respondents in round one, were aged 45 and over) and number of years of experience in current job (73.6% of the participants in round 1 reported having >10 years of experience in their current role), the participants were reasonably senior within their respective organisations. Having greater levels of responsibility associated with more senior positions, and so being particularly engaged with high level work issues, may also have been problematic in terms of second round response attrition.

Women were underrepresented in both rounds with 30% female participants in round 1 and 38% in round 2, which may reflect differences in the extent to which women work in the food safety area. European participants dominated both samples (round 1, 43% and round 2, 52.4%) which are consistent with previous Delphi studies focused on agrifood policy sponsored by the European Commission (Wentholt *et al*, 2010; Wentholt *et al*, 2009).

INSERT TABLE 3 HERE

Consistent with previous Delphi studies focused on agri-food policy funded by the EU Commission (Wentholt *et al*, 2010; Wentholt *et al*, 2009), there was a relatively low response rate from experts residing outside of the EU. In order to permit comparative analysis, respondents were categorised as being 'European'(due to the unitary regulation) or 'International' experts.

3.2 Drivers of existing and emerging food safety risk

In accordance with research question 1) *What are the drivers of existing and emerging food safety risks according to experts?*, descriptive statistical analysis based upon the highest percentage agreement (>60%) was adopted to provide an initial identification of the drivers agreed by experts to increase or decrease exisiting and emerging food safety risks. Seven key drivers of existing and emerging food safety risks were identified: *demographic change, economic driving forces, resource shortages, environmental driving forces, increased complexity of the food supply chain, water security and malevolent activities.* In a second stage, regression analysis was performed to identify the statistically significant drivers of existing and emerging food safety risks (see Table 4). The drivers *economic driving, forces, resource shortages and environmental driving forces*, were statistically significant and could therefore be regarded as the main determinants of both existing and emerging food safety risks. These risks represent both socio-economic and biophysical challenges to the mitigation of food safety risks. Further analysis was conducted to explore whether there was a significant difference between the expert ratings of importance regarding the drivers of existing, compared to emerging, food safety risks. AIC indicated that the distinction between drivers of existing and emerging food safety risk did not explain sufficient variation to justify additional model complexity. It can therefore, be argued that the experts perceive there to be no substantial differences between the drivers of existing and emerging food safety risks, at least for the period under consideration,

and perhaps unsuprisingly, experts regard drivers of exisiting food safety risk to also represent emerging risks.

INSERT TABLE 4 HERE

Multinomal regression was then used explore drivers with significant interactions, in other words, to identify drivers with differences in significance based on a range of expert characteristics. Interactions between drivers and the following variables were explored; region represented by experts, area of expertise, gender and age (see Annex 1 and 2 for analytical outputs). For all models, model selection did not retain interaction terms. Drivers with large coefficients and small standard errors were identified to be the primary determinants of existing and emerging food safety risks. Limited statistically significant interactions were found, although, three drivers of existing food safety risks with statistically significant interactions were identified; *societal values, technological changes and water security*. Perhaps unsurprisingly, drivers of existing risks were also identified to be drivers of emerging risk with singificant interactions, namely *societal values and technological changes.* Additionally, *media representation, political will* were also found to be identified to be drivers of emerging food safety risks with significant interactions.

3.3 Regional differences in drivers of existing and emerging food safety risks and the impacts upon food safety risks

Drivers of existing and emerging food safety risks are likely to have varying impacts in different regions of the world. A lack of statistical power and risk of overfitting the data precluded robust inferential analysis. However, ANOVA (of round 2 data) was conducted to explore whether there was significant difference in the impact of some drivers of existing and emerging food safety risks in different parts of the world. For analysis, expert responses by geographical region were divided into seven 'supra- regions' (Africa (n=6), Asia (n=2), Australasia (n=3), BRICS

(n=3), Europe (n=25), North America (n=1) and South America (n=2)).The impacts of all the drivers on food safety risks was shown to be greatest in Africa compared to other continents (Table 5), although, some caution must be exerted when interpreting this finding given the Eurocentric nature of the sample and the relatively low response rates from international experts.

INSERT TABLE 5 HERE.
INSERT FIGURE 1 HERE

Expert response was also presented as a histogram to explore which specific drivers were considered to be impacting which parts of the world (Figure 1). Visual inspection of Figure 1 highlights there to be regional differences in drivers of existing and emerging food safety risks, and shows that experts may consider some drivers to be more important in some regions compared to others. Whilst some drivers present universal challenges to food safety risks irrespective of region (*i.e. water shortages, demographic change, resource shortages and environmental driving forces*), others are shown to be regionally dependant. For example, the distribution of African expert's responses for the drivers, *the complexity of the food supply chain, malevolent activities and resource shortages*, reflects uncertainty regarding their impact in this region. Asian experts consider all drivers to affect existing and emerging food safety risks in their region, likewise, Australasian experts also consider all drivers to increase food safety risks, with, *the complexity of the food supply chain and environmental driving* forces identified as having most impact in this region. Experts representing BRICS countires appear to be more positve in their estimations reporting marginal decreases in the impact of some drivers particularly the impact of *malevolent activities and resource shortages.* From a policy perspective this indicates the need to ensure that policies are aimed at targeting universal drivers of food safety risks, but also regionally specific drivers to address geographically prevalent risks.

3.4 Direction of impacts of drivers on existing and emerging food safety risks

Understanding the direction of the impact (positive or negative) of the drivers on a range of known food safety risks were explored in the second round Delphi survey. Level of agreement

was taken as a proxy measure of importance. The impacts of drivers on a range of food safety risks were considered for the following: *demographic change, economic driving forces, resource shortages, environmental driving forces, increased complexity of the food supply chain, water security* and *malevolent activitie* (identified through the analysis of descriptive statistics described in Section 3.2.) Figure 2 plots the extent to which experts considered these key drivers of existing and emerging food risk to increase a range of specific food safety risks. Each individual graph represents expert response to the driver and the extent to which experts consider this to be increasing or decreasing specific food safety risks. Figure 2 indicatesthere to be no substantial differences between the drivers of existing and emerging risks and their impact on a range of food safety risks, at least for the period under consideration. This finding further reinforces the arguments that unless mitigated, existing risks are also likely to pose an emerging food safety risk. Further interpretation of Figure 2 suggests that experts consider each driver to be associated with increasing or decreasing multiple food safety risks. It can therefore be argued that there are multiple potential pathways for intervention in order to reduce specific food safety risks. From a policy perspective this is advantageous in that if a particular policy intervention fails, alternative approaches can be implemented. However, if multiple policy approaches are implemented it may be difficult to establish the effectiveness of individual interventions.

INSERT FIGURE 2 HERE

3.5 Barriers to effective food risk identification and mitigation

Table 6 shows there to be little variation in the expert ranking of barriers to existing and emerging food safety risk mitigation policies, according to whether these apply at the national or international level. The barriers were ranked according to low response scores (i.e. mean value close to 1 = agree) and low variation in responses across the sample (indicated by Z-score). Although the prioritization of the barriers to food safety risk identification and mitigation did differ slightly, expert consensus was reached. Five main barriers to effective identification and

management of exisiting and emerging food safety risks globally were; *the lack of harmonisation of regulations between countries, data sharing between institutions, economic pressures on the production chain, poor communication between different actors in the food supply chain,* and *the lack of resources for funding organisations.* This accentuates the expert pereception that there is lack of cohesion in the global governance of food safety risks and emphasises that it is the socio-economic basis, rather than the technical base of risk assessments, that are the primary barriers to risk mitigation. Similarly convergence in disagreement was also identified. Experts believed that the *lack of a responsible food safety agency* and *insufficient enforcement of food safety measures* did not represent barriers to food safety risk identification and mitigation globally. Rather, the challenges were associated with insufficient efforts to harmonise existing food safety risk governance and mitigation structures globally, and improve mechnisms for data sharing between responsible food safety agencies. There was a greater level of variation in response indicated by larger z-scores, which adds additional support to the argument for greater harmonisation of existing governance frameworks, whilst also recognising disparities in capability and capacity to detect and manage food safety risks globally, which was particularly pronounced in some developing world regions. However, the highest mean responses were around the mid-point indicating that experts considered all barriers to be of some importance.

INSERT TABLE 6 HERE

Gaps in current food safety research were identified according to the same approach (low response scores (i.e. mean value close to 1 = agree) and low variation in response across the sample (indicated by Z-score) shown in Table 7. Gaps in research nationally and internationally were identified to be very similar, although, slight differences in prioritisation were observed. For existing food safety risks, experts identified the need for future research to *encompass the entire food chain,* for research to improve existing *risk monitoring,* and for the development of

374 *new detection methods*. Internationally the need for future research to assess *the social impacts*
375 *of food safety risks* was recognized, but this was not considered to be a knowledge gap
376 nationally. Perhaps unsurprisingly, in relation to emerging food safety risks both nationally and
377 internationally, the need for research to *develop new detection methods* to deal with new risks
378 were prioritized, as was research that seeks to understand *the impacts of multiple drivers on food*
379 *safety risks*. Similar patterns in expert disagreement regarding research priorities for exisiting
380 and emerging food safety risks both nationally and internationally were observed. Unanimously,
381 experts gave the lowest priority to research into the use of *Health Adjusted Life Years (HALYS)*
382 in risks assessments. Additionally, experts disagreed on the need for future research to consider
383 a range of aspects relating to food safety risk assessment including research to understand *risk-*
384 *benefit tradeoffs*, *uncertainty reduction in risk models* and *effective risks ranking methodologie*s.
385 This suggests that experts perceive that current risk assessment approaches are adequate and a
386 need for future research to be directed towards risk detection rather than assessment.

387 INSERT TABLE 7 HERE

388 **4. Discussion**

389 This research has demonstrated that, in terms of expert opinion, specific potential
390 drivers of food risk do not increase or decrease specific food safety risks, but that there exists
391 a complex set of interactions which have positive and negative impacts on existing and
392 emerging food risks. Each potential driver is associated with increasing or decreasing
393 multiple food safety risks, and cannot be considered in isolation of other factors, either in
394 research or policy. In order to develop policies to effectively mitigate food safety risks, the
395 adoption of a "systems approach" is needed, which is capable of simultaneously modelling
396 the impacts of multiple drivers, and generating a portfolio policy response based on the
397 impacts of different potential future food safety scenarios. In other words, developing policies

398 which influence a single driver in a single geographic location will have very little impact on
399 existing or emerging food safety risks. Traditional reductionist approaches to delivering
400 evidence for policy makers will not enable the effective translation of policy outcomes to
401 occur. While this conclusion is not novel (see , for example, the global Food Security
402 Programme currently running in the U.K., which prioritises research utilising a systems
403 approach addressing social and biophysical factors influencing food security[3]), the results
404 support the idea that multiple interacting drivers of risk (an important component of food
405 security) need to be considered as part of an evidence base for policy responses. A summary
406 of the reserch findings and relevance for policy developement, is provided in Table 8.

407 INSERT TABLE 8 HERE

408 An important factor shaping the discourse about food security, which also addresses
409 food safety, is the complex, qualitative, and systemic view of the post-agricultural production
410 side of the food system, which emphasises nutrition as well as food availability, and the role
411 of human behaviour (including that associated with producers, the food industry, and
412 consumers). As a consequence, decisions regarding food safety need to be made within this
413 systemic context using diverse information from multiple sources, including stakeholder
414 inputs into models, and identification of relevant knowledge and data. More evidence may be
415 required to reduce uncertainties where these exist, although this needs to be quantified within
416 models. Interventions also require the adoption of a systems approach as is common in other
417 areas of public health policy (Midgley, 2015). The experts prioritised the need for
418 establishing and maintaining national and international food safety agencies, but it is possible
419 that, as a consequence of the interrelationship between food safety and food security, such

[3] http://www.foodsecurity.ac.uk/programme/activities/, accessed 8th September 2016. See also DEFRA. (2010). UK food security assessment: Detailed analysis. London: Defra. http://archive.defra.gov.uk/foodfarm/food/pdf/food-assess100105.pdf, accessed 8th Sepetmber 2016).

agencies might be better placed to manage broad food (and nutrition) security through application of an integrated, coherent policy response, particularly at the international, intergovernmental agency level.

In addition, such a systems sapproach cannot ignore other aspects of food security, as it is likely to interact with food quality on the one hand, and food availability on the other. Understanding this complexity is central to the development of methodologies. For example, the research presented here has demonstrated that climate change is already negatively impacting food production (Shindell *et al*, 2015), and may also have negative impacts on the nutritional quality of food (Mueller Loose and Remaud, 2013). At the same time, malnutrition (including, for example, nutrient intakes, including nutrient needs at different stages the life cycle, and obesity) continues to have negative effects on public health, with disproportionately negative effects on vulnerable groups such as the less affluent, or the elderly (Stow *et al*, 2015).

Simultaneous consideration of food safety and sustainability of production, the energy provided by the diet, and its nutritional quality within the entire food system is required in terms of the evidence generated by research, and its subsequent translation into concrete policies. To be secure, the food system must ensure both supply and demand, and address food safety, quality and availability simultaneously. The balance between supply, cost and environmental impact requires careful consideration to meet the challenge of provision of safe, nutritious food whilst maintaining or enhancing ecosystem services. Given that the food system must be resilient to future shocks (whether these originate in the social or natural environment, and compromise safety or other aspects of food security) a portfolio policy response is required, which will enable flexible responses to predictable, but uncertain, future events.

There were few surprises in terms of expert opinion regarding the barriers to effective food safety risk mitigation. Consistent with previous research (Wentholt *et al*, 2010), the barriers to effective food safety mitigation identified represented the socio-economic rather than the technical basis of risk assessment. Experts believed that an adequate global infrastructure to detect food safety risks and acceptable capabilites globally to enforce regulation currently exists. They also saw inconsistencies with food safety regulation globally as a significant barrier to mitigation of food safety risks. Whilst previous research has suggested that different food safety standards might be applied globally, for example in developing countries (Wentholt *et al*, 2009), the current research suggests an expert preference for increasing food safety standards globally rather than tolerating the application of different standards as the status quo. This will require further national and regional investment, and militates against the principle of 'business as usual'.

5. Limitations

An important limitation of this Delphi survey was the lower level of response from international experts. Although this is consistent with other expert-based agrifood policy research, it makes it difficult to draw firm conclusions regarding the inter-regional differences in expert opinions regarding existing and emerging food safety risks other than those comparing Europe to the rest of the world. Although efforts were made to increase participation of international experts in terms of their responses to the survey, including translating the survey into important global languages, respondents tended to prefer to complete the survey in English. However, a further contributing factor could be over reliance on the (project) stakeholder database as the primary sampling mechanism. Future research might therefore increase response by adopting additional sampling approaches. For example, the use of 'cascade' methodology, utilising the personal contacts of researchers or members of existing policy networks as a basis for sampling, can also help to improve response rates

Formatted: Indent: First line: 1.02 cm, Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

469 in subsequent Delphi rounds, although it can potentially introduce biases into the sampling
470 procedure (Frewer *et al*, 2011).

471 **6. Conclusions**

472 International experts express the opinion that there are, in general, no major differences
473 between the drivers of existing and emerging food safety risks within the timeframe of the
474 next five years. *Demographic change, economic driving forces, resource shortages* and
475 *environmental driving forces* were identified to be drivers of both existing and emerging food
476 safety risks. Limited numbers of interactions were found between the key drivers of existing
477 and emerging risk and specific food safety risks, indicating that existing and emerging food
478 safety risks have the same drivers. Introducing policies which affect a single driver may have
479 impacts on multiple food safety risks. A systems approach to identifying, managing and
480 mitigating food safety risks may therefore represent a useful policy tool. Attempting to
481 manage or mitigate single risks at a single point in time, or within a limited geographical
482 frame, potentially will have limited impacts on global food safety. Finally, the identification
483 of barriers to effective food safety mitigation and future research requirements suggested the
484 need to develop policies which foster sustained international networks and mechanisms for
485 effective data sharing between food safety stakeholders in expert communities globally. This
486 will act to facilitate the international harmonisation of food safety standards globally, rather
487 than tolerate exceptions, which is the approach that has previously been advocated. The need
488 for a holistic approach suggests that some drivers of existing or emerging food safety risks
489 are not necessarily more important in some regions of the world, but rather that the
490 emergence of food safety risks need to be considered from a global perspective. Climate
491 change or economic recession may have global and multiple impacts on emerging food risks
492 for example, but these impacts may be different in different locations and contexts. None-the-
493 less these need to be considered simultaneously. At the same time, various barriers to

494 effective food risk identification and mitigation can be identified. Eliminating these must be a
495 policy priority. Notably the same barriers appear relevant for both existing and emerging food
496 safety risks, and so policy measures designed to address these are likley to be effective in
497 terms of existing and emerging food safety risk identification.
498
499 **Acknowledgements**
500 This project has received funding from the European Union's Seventh Framework
501 Programme for research, technological development and demonstration under grant
502 agreement nº 311611. This paper reflects only the authors' views and the European Union is
503 not responsible for any use that might be made of the content of the information contained in
504 it. We would like to thank the European Commission for funding this research.
505
506 **REFERENCES**

507 Aspinall, W. (2010). A route to more tractable expert advice, *Nature*, 463:pp294–295
508 Athukorala, P.C. and Jayasuriya, S., 2003. Food safety issues, trade and WTO rules: a
509 developing country perspective. The World Economy, 26(9), pp.1395-1416.
510 Baert, K., Van Huffel, X., Jacxsens, L., Berkvens, D., Diricks, H., Huyghebaert, A. and
511 Uyttendaele, M., 2012. Measuring the perceived pressure and stakeholders' response that
512 may impact the status of the safety of the food chain in Belgium. Food research
513 international, 48(1), pp.257-264.
514 Batz, M.B., Hoffmann, S., Morris Jr, J. G. (2012).Ranking the disease burden of 14
515 pathogens in food sources in the United States using attribution data from outbreak
516 investigations and expert elicitation. *Journal of Food Protection*, 75(7):pp1278-1291.

517 Bielenia-Grajewska M. (2015). Metaphors and risk cognition in the discourse on food-borne
518 diseases. Pp. 89-105. In (Eds.) Mercantini, J-M., Faucher, C. Risk and Cognition, Berlin
519 Heidelberg Bolger: Springer.
520 Bizikova, L., Roy, D., Swanson, D., Venema, H.D. and McCandless, M., 2013. The water-
521 energy-food security nexus: Towards a practical planning and decision-support
522 framework for landscape investment and risk management. Winnipeg, Manitoba:
523 International Institute for Sustainable Development.
524 Breckling, B. and Schmidt, G., 2015. Synthetic biology and genetic engineering: Parallels in
525 risk assessment. In Synthetic Biology (pp. 197-211). Springer International Publishing.
526 Bolger, F., Rowe, G. (2015). The aggregation of expert judgment: do good things come to
527 those who weight?. *Risk Analysis*, 35(1):p5..
528 Botting, N., Barnett, J., Gowland, M.H. and Lucas, J.S., 2012. The problems that peanut and
529 tree nut allergic people encounter when travelling abroad. Clinical & Experimental
530 Allergy, 42(12), p.1831.
531 van de Brug, F.J., Luijckx, N.L., Cnossen, H. J., and Houben, G.F. (2014). Early signals for
532 emerging food safety risks: From past cases to future identification. *Food Control*; 39:75-
533 86.
534 Butler, A.J., Thomas, M.K., Pintar, K.D. (2015). Systematic Review of Expert Elicitation
535 Methods as a Tool for Source Attribution of Enteric Illness, *Foodborne Pathogens and*
536 *Disease*, 12(5):pp367-382.
537 Caduff, L. and Bernauer, T., 2006. Managing risk and regulation in European food safety
538 governance. Review of Policy Research, 23(1), pp.153-168.
539 Cooke, R.M. (2015). The aggregation of expert judgment: do good things come to those who
540 weight?, *Risk Analysis*, 35(1):pp12-15.

541 Crandall, P., Van Loo, E.J., O'Bryan, C.A., Mauromoustakos, A., Yiannas, F., Dyenson, N.,
542 Berdnik, I. (2012). Companies' opinions and acceptance of Global Food Safety Initiative
543 benchmarks after implementation, *Journal of Food Protection*, 75(9):pp1660-1672.
544 Davidson, R.K., Romig, T., Jenkins, E., Tryland, M. and Robertson, L.J., 2012. The impact
545 of globalisation on the distribution of Echinococcus multilocularis. Trends in
546 parasitology, 28(6), pp.239-247.
547 Dicks, L., Hodge, I., Randall, N.P., Scharelmann, J.P.W., Siriwardena, G.M., Smith, H.G.,
548 Smith, H.G., Smith, R.K., Sutherland, W.J. (2014). A Transparent Process for "Evidence-
549 Informed" Policy Making, Conservation Letters, March/April 2014, 7(2), pp119–125.
550 Ercsey-Ravasz, M., Toroczkai, Z., Lakner, Z., Baranyi, J. (2012). Complexity of the
551 international agro-food trade network and its impact on food safety, *PLoS One* 7(5).
552 FAO. (2006). *The state of food and agriculture 2006, Food Aid for Food Security*? Food and
553 Agriculture Organisation of the United Nations, Available at
554 http://www.fao.org/docrep/009/a0800e/a0800e00.HTM, Accessed 12th July 2015.
555 Feskens, E., Frewer, L.J., Gregory, P., Grusak, M., Scholten, P. (2015). FACCE JPI – *JPI*
556 *HDHL Priority Joint Actions to contribute to the European Strategy on Food and*
557 *Nutrition Security Outcomes of the Grand Debate "Nutrition Security – A whole system*
558 *approach*". Available at http://www.healthydietforhealthylife.eu/images/FACCE-JPI-
559 HDHLcontributiononfoodandnutritionsecurity_31-August-2015_formatted_final.pdf
560 Accessed September 2015.
561 Fischer, A.R.H., Wentholt, M.T.A., Rowe, G., Frewer, L.J. (2014). Expert involvement in
562 policy development: A systematic review of current practice. *Science and Public Policy*;
563 41:pp332-343.
564 Flachowsky, G., Schafft, H. and Meyer, U., 2012. Animal feeding studies for nutritional and
565 safety assessments of feeds from genetically modified plants: A review. Journal für

566 Verbraucherschutz und Lebensmittelsicherheit, 7(3), pp.179-194Frewer, L.J., Fischer,
567 A.R.H., Brennan, M., Bánáti, D., Lion, R., Meertens, R.M., Vereijken, C.M.J.L. (in
568 press). Risk/benefit communication about food–a systematic review of the literature.
569 *Critical Reviews in Food Science and Nutrition*.
570 Frewer, L.J., Fischer, A.H.R., Wentholt, M.T.A., Marvin, H.J.P., Ooms, B.W., Coles, D.,
571 Rowe, G. (2011).The use of Delphi Methodology in Agrifood Policy Development: Some
572 lessons learned, *Technological Forecasting and Social Change*, 78:pp1514-1525.
573 Gordon, T. and Pease, A., 2006. RT Delphi: An efficient,"round-less" almost real time
574 Delphi method. Technological Forecasting and Social Change, 73(4), pp.321-333.
575 Havelaar, A.H., Brul, S., De Jong, A., De Jonge, R., Zwietering, M.H., Ter Kuile, B.H.
576 (2010). Future challenges to microbial food safety. *International Journal of Food*
577 *Microbiology*, 139:S79-S94.
578 Havelaar, A.H., Cawthorne, A., Angulo, F., Bellinger, D., Corrigan, T., Cravioto, A.,
579 Kuchenmüller, T. (2013). WHO initiative to estimate the global burden of foodborne
580 diseases, *The Lancet*, 381:S59.
581 Hoffmann, S.A., Fischbeck, P.S., Krupnick, A.J., McWilliams, M. (2006). Eliciting
582 Information on Uncertainty from Heterogeneous Expert Panels: Attributing US
583 Foodborne Pathogen Illness to Food Consumption, *AgEcon discussion paper* Available at
584 http://purl.umn.edu/10444. Accessed September 2015.
585 Jacobs, S., Sioen, I., Pieniak, Z., De Henauw, S., Maulvault, A.L., Reuver, M., Fait, G.,
586 Cano-Sancho, G., Verbeke, W. (in press). Consumers' health risk–benefit perception of
587 seafood and attitude toward the marine environment: Insights from five European
588 countries. *Environmental Research.*
589 Jensen, H.G., Jensen, J.D. (2013). Vaccination of poultry against Campylobacter in the EU:
590 what are the economic benefits?, *Food Economics*, 9(sup5):1-10.

591 Jespersen, M., Halberg, N. (2012). Coordination of European transnational research in
592 organic food and farming. *A decade of EU-funded, low-input and organic agriculture*
593 *research (2000-2012)*, pp26-43.
594 Johnson, R.L., Koeritzer, R.E. (2012). Testing with Confidence in the Pursuit of Global Food
595 Safety. In Eds. Ellefson, W. Zach
596 Jia, C., Jukes, D. (2013). The national food safety control system of China - A systematic
597 review, *Food Control*, 32(1):pp236-245.
598 Käferstein, F., Abdussalam, M. (1999). Food safety in the 21st century. *Bulletin of the World*
599 *Health Organization*, 77(4):p347.
600 Kaptan, G., Hubbard, C., Frewer, L.J. (2013). *Collab4safety Project Towards sustainable*
601 *global food safety collaboration*, Deliverable 1.1 - Report on the scoping workshop.
602 Available at:
603 http://web.spi.pt/collab4safety/sites/default/files/Scoping%20workshop%20report.pdf.
604 Kendall, H., Kaptan, G., Stewart, G., Hubbard., C., Raley, M., and Frewer., L.J. (2015).
605 *Collab4safety Project Towards sustainable global food safety collaboration*, Deliverable
606 1.2- Delphi report. Available at: http://web.spi.pt/collab4safety/download-area/reports
607 Kennedy, S. (2012). *Emerging global food system risks and potential solutions. Improving*
608 *Import Food Safety*. Hoboken: John Wiley and Sons, Inc.
609 Kher, V.S., Frewer, L.J., Wentholt, M.T.A., Howell-Davies, O., Lucas, N.B., Cnossen, L.H.J.
610 (2010). Experts perspectives on the implementation of traceability in Europe, *British*
611 *Food Journal*, 112(3):pp261-274.
612 Kim, K.K., O'Bryan, C.A., Crandall, P.G., Ricke, S.C., Neal, J.(2013). Identifying baseline
613 food safety training practices for retail delis using Delphi expert consensus method, *Food*
614 *Control*, 32(1):pp55-62.

615 Krystallis, A., Frewer, L., Rowe, G., Houghton, J., Kehagia, O., Perrea, T. (2007). A
616 perceptual divide? Consumer and expert attitudes to food risk management in Europe.
617 *Health, Risk and Society*, 9(4):pp407-424.
618 Krayer von Krauss, M.P., Casman, E.A., Small, M.J. (2004). Elicitation of Expert Judgments
619 of Uncertainty in the Risk Assessment of Herbicide-Tolerant Oilseed Crops, *Risk*
620 *Analysis*, 24(6):1515-1527.
621 König, A., Kuiper, H.A., Marvin, H.J., Boon, P.E., Busk, L., Cnudde, F., Cope, S., Davies,
622 H.V., Dreyer, M., Frewer, L.J. and Kaiser, M., 2010. The SAFE FOODS framework for
623 improved risk analysis of foods. Food Control, 21(12), pp.1566-1587.
624 Ladics, G.S., Bartholomaeus, A., Bregitzer, P., Doerrer, N.G., Gray, A., Holzhauser, T.,
625 Glenn, K. (2015). Genetic basis and detection of unintended effects in genetically
626 modified crop plants, *Transgenic Research*, 24 (4):587-603.
627 Landeta, J., Barrutia, J. and Lertxundi, A., 2011. Hybrid Delphi: A methodology to facilitate
628 contribution from experts in professional contexts. Technological Forecasting and Social
629 Change, 78(9), pp.1629-1641.
630 Lee, J., Gereffi, G., Beauvais, J. (2012). Global value chains and agrifood standards:
631 challenges and possibilities for smallholders in developing countries, *Proceedings of the*
632 *National Academy of Sciences*, 109(31):12326-12331.
633 Li, L., Zhou, Z., Jin, W., Wan, Y., Lu, W. (2015). A transcriptomic analysis for identifying
634 the unintended effects of introducing a heterologous glyphosate-tolerant EPSP synthase
635 into Escherichia coli, *Molecular BioSystems*, 11(3):852-858.
636 Linstone, H.A. and Turoff, M. eds., 1975. The Delphi method: Techniques and applications
637 (Vol. 29). Reading, MA: Addison-Wesle
638 Loeber, A., Hajer, M., Levidow, L. (2011). Agro-food crises: Institutional and discursive
639 changes in the food scares era. *Science as Culture*, 20(2):147-155.

640 Lu, Y., Jenkins, A., Ferrier, R.C., Bailey, M., Gordon, I.J., Song, S., Huang, J., Jia, S., Zhang,
641 F., Liu, X. and Feng, Z., 2015. Addressing China's grand challenge of achieving food
642 security while ensuring environmental sustainability. Science advances, 1(1), p.e1400039.
643 Lund, B.M. and O'Brien, S.J., 2011. The occurrence and prevention of foodborne disease in
644 vulnerable people. Foodborne pathogens and disease, 8(9), pp.961-973.
645 Marucheck, A., Greis, N., Mena, C., Cai, L. (2011). Product safety and security in the global
646 supply chain: Issues, challenges and research opportunities. *Journal of Operations*
647 *Management*, 29(7):707-720.
648 Marvin, H.J.P., Kleter, G.A., Frewer, L.J., Cope, S., Wentholt, M.T.A., Rowe, G. (2009). A
649 working procedure for identifying emerging food safety issues at an early stage:
650 Implications for European and international risk management practices. *Food Control*;
651 20(4):345-356.
652 Marvin, H.J., Kleter, G.A., Noordam, M.Y., Franz, E., Willems, D.J. and Boxall, A., 2013.
653 Proactive systems for early warning of potential impacts of natural disasters on food
654 safety: Climate-change-induced extreme events as case in point. Food Control, 34(2),
655 pp.444-456
656 Meunier, S., Nicolaidis, K. (2006). The European Union as a conflicted trade power. *Journal*
657 *of European Public Policy*, 13(6): pp906-925.
658 Midgley, G. (2015). Systemic Intervention. In (Eds.) Reason, P, Bradbury, H. *The Handbook*
659 *of Action Research*. 2nd Edition. Bradbury-Huang, H. (ed.). London: Sage.
660 Milne, R., 2011. A focus group study of food safety practices in relation to listeriosis among
661 the over-60s. Critical Public Health, 21(4), pp.485-495.
662 More. S.J., McKenzie, K., O'Flaherty, J., Doherty, M.L., Cromie, A.R., Magan, M.J. (2010).
663 Setting priorities for non-regulatory animal health in Ireland: results from an expert

664 Policy Delphi study and a farmer priority identification survey. *Preventive Veterinary*
665 *Medicine*, 95(3):pp198-207.
666 Morgan, M.G. (2014). Use (and abuse) of expert elicitation in support of decision making for
667 public policy. *Proceedings of the National Academy of Sciences*, 111(20):pp7176-7184.
668 Mueller Loose, S., Remaud, H. (2013). Impact of corporate social responsibility claims on
669 consumer food choice: A cross-cultural comparison, *British Food Journal*, 115(1):
670 pp142-166.
671 Oken, E., Choi, A.L., Karagas, M.R., Mariën, K., Rheinberger, C.M., Schoeny, R., Schoeny,
672 R., Sunderland, E., Korrick, S. (2012). Which fish should I eat? Perspectives influencing fish
673 consumption choices. *Environmental Health Perspectives*, 120(6):790.
674 Pennings, J.M., Wansink, B., Meulenberg, M.T. (2002). A note on modeling consumer
675 reactions to a crisis: The case of the mad cow disease. *International Journal of Research*
676 *in Marketing*, 19(1):91-100
677 Percy, B. (2011). GFSI compliance and automated food safety management systems: a
678 harmonized risk-based solution for food safety, *Cereal Foods World*, 56(4):pp144-146.
679 Prakash, J. (2014). The challenges for global harmonisation of food safety norms and
680 regulations: issues for India. *Journal of the Science of Food and Agriculture*;
681 94(10):1962-1965.
682 Pöting, A., Schauzu, M., Niemann, B. and Schumann, R., 2014. Risk Assessment of Novel
683 Food and Genetically Modified Food and Feed. In Regulatory Toxicology (pp. 827-848).
684 Springer Berlin Heidelberg.
685 Robertson, L.J., Sprong, H., Ortega, Y.R., van der Giessen, J.W. and Fayer, R., 2014. Impacts
686 of globalisation on foodborne parasites. Trends in parasitology, 30(1), pp.37-52.
687 Rowe, G., Wright, G. and Bolger, F., 1991. Delphi: a reevaluation of research and theory.
688 Technological forecasting and social change, 39(3), pp.235-251.

689 Schwägele, F. (2005). Traceability from a European perspective, *Meat Science*, 71(1):164-
690 173.
691 Schmidhuber, J. and Tubiello, F.N., 2007. Global food security under climate change.
692 Proceedings of the National Academy of Sciences, 104(50), pp.19703-19708.
693 Shindell, D.T., Faluvegi, G., Rotstayn, L., Milly, G. (2015). Spatial patterns of radiative
694 forcing and surface temperature response. *J. Geophys. Res. Atmos.*, 120(11):pp5385-
695 5403, doi:10.1002/2014JD022752.
696 Skovgaard, N. (2007). New trends in emerging pathogens. *International Journal of Food*
697 *Microbiology*, 120(3):217-224.
698
699 Smith, B.A., Ruthman, T., Sparling, E., Auld, H., Comer, N., Young, I., Lammerding, A.M.
700 and Fazil, A., 2015. A risk modeling framework to evaluate the impacts of climate change
701 and adaptation on food and water safety. Food Research International, 68, pp.78-85.
702 Soon, J.M., Davies, W.P., Chadd, S.A., Baines, R.N. (2012). A Delphi-based approach to
703 developing and validating a farm food safety risk assessment tool by experts. *Expert*
704 *Systems with Applications*, 39(3):pp8325-8336.
705 Spink, J., Moyer, D.C. (2011). Defining the public health threat of food fraud. *Journal of*
706 *Food Science*; 76(9):157-163.
707 Stow, R., Ives, N., Smith, C., Rick, C.M. Rushton, A. (2015). Cluster randomised fesability
708 trial evaluating nutriational interventions in the treatment of malnutriation in care home
709 adult residents. *Trials*, 16:433; doi:10.1186/s13063-015-0952-2.
710 Strohbehn, C.H., Gilmore, S.A., Sneed, J. (2004). Food safety practices and HACCP
711 implementation: perceptions of registered dietitians and dietary managers. *Journal of the*
712 *American Dietetic Association*, 104(11):pp1692-1699.

713 Sundström J.F., Albihn, A,. Boqvist, S., Ljungvall, K., Marstorp, H., Martiin, C., Magnusson,
714 U. (2014). Future threats to agricultural food production posed by environmental
715 degradation, climate change, and animal and plant diseases–a risk analysis in three
716 economic and climate settings. *Food Security*; 6(2):201-215.
717 Takeuchi, M.T., Kojima, M. and Luetzow, M., 2014. State of the art on the initiatives and
718 activities relevant to risk assessment and risk management of nanotechnologies in the
719 food and agriculture sectors. Food Research International, 64, pp.976-981.
720 Timmer, C.P., 2012. Behavioral dimensions of food security. Proceedings of the National
721 Academy of Sciences, 109(31), pp.12315-12320.
722 Turoff, M., 1970. The design of a policy Delphi. Technological forecasting and social
723 change, 2(2), pp.149-171.
724 USDA. (2015) http://www.usda.gov/wps/portal/usda/usdahome?navid=food-safety. Accessed
725 27th July 2015.
726 Venables, W.N., Ripley, B.D. (2002). *Modern applied statistics with S*. Fourth Edition.
727 Springer, New York.
728 Vermeulen, S.J., Campbell, B.M. and Ingram, J.S., 2012. Climate change and food systems.
729 Annual Review of Environment and Resources, 37.
730 Weible, C.M. (2008). Expert-based information and policy subsystems: a review and
731 synthesis, *Policy Studies Journal*, 36(4): pp615-635.
732 Wentholt, M.T.A., Cardoen, S., Imberechts, H., Van Huffel, X., Ooms, B.W., Frewer, L.J.
733 (2012). Defining European preparedness and research needs regarding emerging
734 infectious animal diseases: Results from a Delphi expert consultation. *Preventive*
735 *Veterinary Medicine*, 103(2):pp81-92.

Wentholt, M.T.A., Fischer, A.R.H., Rowe, G., Marvin, H.J.P., Frewer, L.J. (2010). Effective identification and management of emerging food risks: Results of International Delphi Survey, *Food Control*, 21:pp1731-1738.

Wentholt, M.T.A., Rowe, G., König, A., Marvin, H.J.P., Frewer, L.J. (2009).The views of key stakeholders on an evolving food risk governance framework: results from a Delphi study, *Food Policy*, 34(6): pp539-548.

Wahlqvist, M.L., McKay, J., Chang, Y.C. and Chiu, Y.W., 2012. Rethinking the food security debate in Asia: some missing ecological and health dimensions and solutions. Food Security, 4(4), pp.657-670.

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York.

Wu, Y., Chen Y. (2013). Food safety in China. *Journal of Epidemiology and Community Health*; 67(6):478-479.

Zhang, Y., Bi, P., Hiller, J. (2008).Climate variations and salmonellosis transmission in Adelaide, South Australia: a comparison between regression models. *International Journal of Biometeorology*, 52(3):179-187.

Table 1: Drivers of existing and emerging food safety risks

Driver of emerging food risk	Concrete examples of driver	Examples of impacts	Example References
Demographic change	Population growth Ageing Migration	Food insecurity may increase consumption of unsafe foods. Ageing may result in increased vulnerability to food risks. Migration may expose populations to different food allergens in local food chains to which they are genetically susceptible.	Athukorala and Jayasuriya (2003) Barnett, Botting, Gowland, and Lucas (2012) Lund and O'Brien (2011) Milne (2011)
Economic driving forces	Globalisation of the food web Food prices	Increased globalisation means tracking foods and ingredients becomes more complex, as does identifying any associated food safety issues. Increased food prices may result in consumers eating unsafe foods.	Baert, Van Huffel, Jacxsens, Berkvens, Diricks, Huyghebaert, and Uyttendaele (2012) Davidson, Romig, Jenkins, Tryland, and Robertson (2012) Robertson, Sprong, Ortega, van der Giessen, and Fayer (2014) Timmer (2012)
Resource shortages	Energy Land	Pressures on land and energy resources may result in reduced food availability which may have negative effects on food safety as food becomes more scarce.	Bizikova, Roy, Swanson, Venema, and McCandless (2013) Lu, Jenkins, Ferrier, Bailey, Gordon, Song and Zhang, (2015) Wahlqvist, McKay, Chang and Chiu (2012)
Environmental driving forces	Response to and mitigation of climate change Resource scarcity and use efficiency	Emergence of new food safety threats (e.g. mycotoxins). Pressures on land and energy resources may result in reduced food availability which may have negative effects on food safety as food becomes more scarce.	Vermeulen, Campbell and Ingram (2012) Marvin, Kleter, Noordam, Franz, Willems, and Boxall (2013) Schmidhuber, and Tubiello (2007) Smith, Ruthman, Sparling, Auld, Comer, Young, and Fazil, (2014)
Technological advances	Use of genetic modification, nanotechnology or synthetic biology in food production	Introduction of novel technologies may inadvertently introduce new risks including the use of novel organisms as animal feed, potential unintended impacts on human and animal health, plant health and the environment, etc.	Breckling and Schmidt (2015) Domingo and Giné Bordonaba, (2011) Flachowsky, Schafft and Meyer (2012) Pöting, Schauzu, Niemann and Schumann (2014) Takeuchi, Kojima and Luetzow, (2014)
Geopolitical driving forces	Governance, ("hard" versus "soft") Regulatory measures	Lack of harmonisation of standards may result in differences in food safety measures in different parts of the world. A need has been recognised to improve collaboration between	Caduff and Bernauer (2006) König, Kuiper, Marvin, , Boon, Busk., Cnudde and Wentholt (2010)

	War	international experts and institutions. War may cause food safety problems associated with resource shortages.	Marvin, Kleter, Prandini, Dekkers and Bolton (2009) Misselhorn (2005) Wentholt, Rowe , König, Marvin, and Frewer (2009)
Societal values	Values associated with: - human health - animal health - fair trade - environmental protection - corporate social responsibility)	Various societal concerns may represent an important factor in determining the acceptability or otherwise of different potential food hazards.	Frewer, van der Lans, Fischer, Reinders, Menozzi, Zhang, and Zimmermann (2013) Grunert, Hiekeand Wills(2014) Ingenbleek, and Immink (2011) Mueller Looseand Remaud (2013)
Consumer priorities	Behaviours linked to consumer values Risk/benefit perceptions Fair trade Health Animal welfare Environmental protection	Consumers may reject products which do not align with their values, for example in terms of how the foods were produced.	Frewer, van der Lans, Fischer, Reinders, Menozzi, Zhang and Zimmermann (2013) For other references see societal values.
Malevolent activities	Fraud and introduction of counterfeit products Bioterrorism	Food risks may be introduced into the food chain in order to increase economic gains or disrupt economic activities. Food risks may be introduced into the food chain with the intention of causing health, environmental or economic harm.	Croall (2012) Khan, Swerdlow and Juranek (2001) Moore, Spink and Lipp (2012) O'Mahony (2013) van Rijswijk, Frewer, Menozzi and Faioli (2008)
Increased complexity and size of the supply chain	Inclusion of banned ingredients in different supply chains, through lack of international harmonisation of activities	As foods, and in particular food ingredients become more difficult to trace owing to increased food chain complexity, identifying existing and emerging food risks will also become more complex.	Fink-Gremmels,(Ed.) (2012) Jones (2002) Handford, Elliott, and Campbell (2015) He, Xie, Zhang, Zhang, Wang, Liu, and Du (2015) Lindberg, Grimes and Giles (2005) van Egmond (2004)
Food risk representation in the media	Increasing or decreasing societal concern about specific food risks	High levels of media attention on a particular food safety issue may amplify (increase) or attenuate (reduce) the perceptions of the risk in a direction not matched by risk ranking prioritisation.	Frewer, Miles and Marsh (2002) Kuttschreuter, Rutsaert, Hilverda, Regan, Barnett and Verbeke (2014) Rutsaert, Pieniak, Regan, McConnon, Kuttschreuter, Loresand Verbeke (2014) Shan, Regan, De Brún, Barnett, van der Sanden, Wall and McConnon (2013)

Water security	Drought Pollution Flooding Pollution	May increase food insecurity which will link with emerging food risks. Pressure on resources may result in reduced food availability which may have negative effects on food safety as food becomes more scarce.	Cook and Bakker (2012) Lam, Remais, Fung, , Xu and Sun(2013) Lu, Song, Wang, Liu, Meng, Sweetman...and Wang (2015) Stratigea and Giaoutzi (2012) Warner and Afifi (2014)
Political will	Not allocating resources or policy agendas to food safety issues		Wentholt, Fischer, Rowe, Marvin and Frewer (2010)

Table 2: Delphi survey composition

Questions included in the survey (rounds 1 and 2)	
Round 1 survey	
Section Number	**Section title and content**
1.0	**Introduction to the objectives of the survey, and contact details of researchers**
1.1	**Drivers of existing food risks** Participants were asked to indicate whether, in their opinion, each of the drivers listed in Table 1 would decrease or increase existing food risks. Participants were asked to indicate responses on a 5 point scale, anchored by 1= "decrease greatly" and 5="increase greatly". Participants were asked to indicate how certain or uncertain they were for each response given the current state of scientific knowledge. Response was given on a 5 point scale anchored by 1= "extremely", and 5="uncertain". Using an open–ended response, participants were also asked to indicate, , whether any drivers were missing from the list.
1. 2	**Drivers of emerging food risks** Participants were asked to indicate whether, in their opinion, each of the drivers listed in Table 1 would decrease or increase emerging food risks (defined as those occurring within a 5 year time frame). As for Section 1.1, participants were asked to indicate responses on a 5 point scale, anchored by 1= "decrease greatly "and 5 ="increase greatly". Participants were asked to indicate how certain or uncertain they were for each response given the current state of scientific knowledge. Response was given on a 5 point scale anchored by 1="extremely certain", and 5= "uncertain". Using an open–ended response, pParticipants were also asked to indicate, using an open–ended response, whether any drivers were missing from the list.
1.3	**Existing food risks 'national'** Participants were asked to indicate whether they "agreed", "neither agreed nor disagreed", or "disagreed", that each of the following food risks were "important in your country": *"toxicological risks", "microbiological risks", veterinary drug residues",aAntibiotic use in animals", "risky consumer behaviours", "zoonoses", "plant diseases", "artificial growth hormones", "unintended effects of new technologies", "mycotoxins", "radioactive contamination", pPlant pests", "pesticide residues", pPollutants unrelated to agricultural production", "growth hormones in animal production".* Participants were also asked to indicate whether were there were any other existing food risks which should be included (open ended response).
1.4	**Existing food risks 'global'** Participants were asked to indicate whether they "agreed", "neither agreed nor disagreed", or "disagreed", that each of the food risks listed under Section 1.3 were "important globally ": Participants were also asked to indicate whether were there were any other existing food risks which should be included (open ended response).
1.5	**Emerging food risks 'national'** The questions asked under 1.4, above, were repeated for "emerging national food risks" (i.e. those which will occur during the next 5 years).
1.6	**Emerging food risks 'global'** The questions asked under 1.5 above, were repeated for "emerging global food risks" (i.e. those which will occur during the next 5 years).
1.7	**National research gaps for existing risks** Participants were asked to indicate the extent to which they "agreed", "neither agreed or disagreed", or "disagreed" that each of the following represented gaps in current research regarding the mitigation of existing food risks in their country;*"new horizon scanning methods", "new detection methods", "methods of risk assessment (e.g. probabilistic assessment", "gaps in current risk assessment methods regarding what risks are assessed", "predictive methodologies", "understanding social impacts of food riskse.g. employment, human population migration", "understanding effective food risk governance", "research encompassing the entire food chain", "research into the impact of human behaviour", "lack of effective risk ranking methodologies", "understanding risk-benefit trade-offs", "understanding economic impacts of food risks, e.g. changes in financial resources, impacts on trade", "Use of HALYS , (Health Adjusted Life Years, e.g. QALYS", "interdisciplinary research focused on problem resolution", "uncertainty reduction", "interactions between different drivers".* Participants were also asked to indicate whether were there were any other research gaps which should be included (open ended response).

1.8	**International research gaps for existing risks** The questions asked under 1.7 (above) were repeated for international research gaps for existing risks. I.e. those that will occur within the next 5 years.
1.9	**National research gaps for emerging risks** The questions asked under 1.7 (above) were repeated for international research gaps for emerging risks at the national level. I.e. those that will occur within the next 5 years**.**
1.10	**International research gaps for emerging risks** The questions asked under 1.7 (above) were repeated for international research gaps for emerging risks at the international level. I.e. those that will occur within the next 5 years.
1.11	**National policy gaps, existing food risks** Participants were asked to indicate whether they "agreed, "neither agreed nor disagreed", or disagreed", following issues represented important barriers to effective identification and mitigation of existing food risks in your country"; *"lack of harmonisation of regulations between countries", "political will", "few skilled professionals in food safety", "infrastructure", "data sharing between institutions", "duplication of effort", "ineffective incentivisation to producers to apply food safety measures", "inefficient enforcement of food safety measures", "ineffective knowledge exchange between affluent and less affluent countries", "use of different risk assessment methods in different institutions", "economic recession", "poor communication bewtween different actors in the food chain"and "economic pressures on the production chain".* Participants were also asked to indicate whether were there were any other barriers which should be included (open ended response).
1.13	**International policy gaps, existing food risks** The questions asked under Section 1.11 (above), were repeated for international policy gaps.
1.14	**National policy gaps, emerging food risks** The questions asked under 1.11 (above) were repeated for emerging food risks.
1.15	**International policy gaps, emerging food risks** The questions asked under 1.11 (above), were repeated for international policy gaps regarding emerging food risks.
1.16	**Participant background data (summarised in Table 4)**
Round 2 survey	
2.0	**Introduction to the objectives of the survey, and contact details of researchers**
2.1	**Impacts of drivers on existing global food risks** Participants were asked to indicate whether they thought each key driver identified in round 1 together with the open–ended responses (under 1.3, above). (i.e. 'demographic change', 'economic driving forces', 'resource shortages', 'environmental driving forces', 'increased complexity and size of the food supply chain', 'water security', 'malevolent activities') would increase or decrease each of the following existing global food risks. Response was measured on a 5 point scale anchored by 1= "decrease greatly",and 5= "increase greatly" (new or reformatted risks are indicated in bold). The risks included "***toxicological risks chemical risks****", "****toxicological biological risks (mycotoxins, phytotoxins, phycotoxins)",*** *"microbiological risks", "veterinary drug residues", "antibiotic resistance", "risky consumer behaviours", "zoonoses", "plant diseases", "****unintended effects of GM****", "****untended effects of nanotechnology",*** *"****unintended effects of other new technologies****", "artificial growth hormones", "radioactive contamination", "plant pests", pPesticide residues", "pollutants unrelated to agricultural production", "growth hormones in animal production"*.. Participants could also add any additional comment as an open ended response.
2.2	**Impacts of drivers on emerging global food risks** The questions asked under 2.1, above, were repeated for emerging food risks (i.e. those that will occur in the next 5 years).
2.3	**Capacity building (open-ended responses)**
2.3.1	**Skills** Based on the results of round 1, participants were asked the following question: *In Round 1 we asked about the barriers to effective identification and mitigation of food risks. In relation to existing food risks, 47% agreed that in their country there are few skilled professionals in food safety. (A further 43% neither agreed nor disagreed.) We now want to identify those skill shortages more precisely.* • *Please tell us about the training needs in your country with regard to food safety.* • *Please indicate the disciplines in which it is important to increase the amount of training activities. Include both single subject and interdisciplinary training.* • *Please indicate the disciplines in which it is important to increase the amount of training activities internationally with regard to food safety. Again, include both single subject and interdisciplinary training.*

2.3.2	**Other resources** Based on the results of round 1, participants were asked the following question: *Organisations involved in food safety will require resources. However in round 1, 77% agreed that, in their country, there was a lack of funding (from government, industry, NGOs etc.) in relation to identification and mitigation of existing food risks. The figure is slightly lower (73% agree) for emerging risks. 63% agreed that internationally there is a lack of funding.* • *In your country, which activities do you believe are severely constrained due to a lack of funding?* • *Internationally, which activities do you believe are severely constrained due to a lack of funding?*
2.3.3	**Enforcement** Based on the results of round 1, participants were asked the following question: *In Round 1, 56% agreed that in their country there was insufficient enforcement of food safety measures. 59% agreed this was the case internationally.* • *What changes could be made to strengthen the enforcement of food safety regulations in your country?* • *What changes could be made to strengthen the enforcement of food safety regulations internationally?*
2.3.4	**Food fraud** Food fraud had been mentioned as an important issue in the round 1. The issue was further investigated in round 2. Participants were asked to indicate the extent to which they agreed or disagreed with the following statements. Response was measured on a on a 5 point scale, anchored by 1=strongly agree, and 5=strongly disagree. • *Please indicate the extent to which you agree or disagree that food fraud that results in the sale of potentially harmful food, is an important existing food safety risk in your country*. • *Please indicate the extent to which you agree or disagree that food fraud that results in the sale of potentially harmful food, is an important existing food safety risk globally.* • *Please indicate the extent to which you agree or disagree that food fraud that results in the sale of potentially harmful food, is an important emerging food safety risk in your country*. • *Please indicate the extent to which you agree or disagree that food fraud that results in the sale of potentially harmful food, is an important emerging food safety risk globally*. • *To what extent do you agree that there is sufficient capacity in your country to detect potentially harmful food fraud?* • *To what extent do you agree that there is sufficient capacity internationally to detect potentially harmful food fraud?*
2.3.5	**Participant background data (summarised in Table 4)**

Table 3: Sample characteristics

Completed surveys received	Response rate (%)	Age distribution (%)		Gender distribution	Type of organisation (%)		Region (%)		Work experience In current job (%)	
Delphi survey round one										
106	21.0	20-35 years	13.1	30% women	Academic/research	50.0	Europe	43.0	0-5 years	8.0
		36-45 years	30.0		Food industry	8.5	North America	9.5	6-10	17.9
		46-55 Years	26.2		Food regulatory agency	8.5	South America	5.7	11-15 years	16.0
		56-65 years	24.3		Food safety authority	7.5	Asia	7.6	16-20 years	17.9
		Over 65 years	6.5		Multinational organization	0.9	Africa	9.5	21-25 years	8.0
					NGO	6.6	Australasia	8.5	26-30 years	13.2
					Policy maker	0.9	BRICS countries	16.0	31-35 years	7.5
					Other	17.0			36-40 years	1.9
									> 40 years	8.5
Delphi survey round two										
42	40.5 % (of the 106 participants who completed surveys in the first round).	20-35 years	7.1	38% women	Academic/research	Included as other	Europe	52.4	0-5 years	8.5
		36-45 years	28.6		Food industry	14.3	North America	4.8	6-10	17.9
		46-55 Years	38.1		Food regulatory agency	2.4	South America	9.5	11-15 years	16.0
		56-65 years	21.4		Food safety authority	2.4	Asia	4.8	16-20 years	17.9
		Over 65 years	4.8		Multinational organization	-	Africa	14.3	21-25 years	8.5
					NGO	14.3	Australasia	7.1	26-30 years	13.2
					Policy maker	-	BRICS countries	7.1	31-35 years	7.5
					Other	66.7			36-40 years	1.9
									> 40 years	8.5

Note: Academic/research was treated separately in the second round as participants provided feedback that they found it difficult to answer in round one. They were included in the “other “category.

Table 4: Results of regression for driver of existing/emerging food safety risk

Driver name	***b***	**SE *b***	***p***
Demographic change	0.397	0.009	0.000
Economic driving forces	-0.0197	0.014	0.000
Resource shortages	0.0135	0.014	0.336
Environmental driving forces	-0.0979	0.014	0.160
Technological changes	-0.1125	0.014	0.000
Geopolitical driving forces	-0.1947	0.014	0.000
Societal values	-0.0142	0.014	0.000
Consumer priorities	-0.0802	0.014	0.000
Malevolent activities	-0.0156	0.014	0.267
Increased complexity of the food supply chain	-0.0104	0.014	0.460
Food risk representation in the media	-0.0073	0.014	0.000
Water security	-0.0073	0.014	0.605
Political will	-0.1042	0.014	0.000

Table 5: Regression geographical variance in impact of drivers on food safety risks

Continent	***b***	**SE *b***	***p***
Africa	0.321	0.025	0.000
BRICS	0.078	0.043	0.000
Europe	0.041	0.028	0.01
South America	0.036	0.039	0.000
Asia	0.027	0.050	0.000
North America	0.025	0.050	0.000
Australasia	0.012	0.043	0.000

Table 6: Barriers to mitigation of existing and emerging food safety risks

Existing food safety risk: National barriers to mitigation				
Barriers	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-score**
Lack of resources of funding organizations	1.33	1	0.658	0.502
Economic pressures on the production chain	1.36	1	0.589	0.611
Data sharing between institutions	1.44	1	0.667	0.660
Lack of harmonization of regulations between countries	1.49	1	0.707	0.693
Poor communication between different actors in the food chain	1.45	1	0.604	0.745
Lack of enforceable regulations	1.68	1	0.834	0.815
Insufficient knowledge transfer from affluent countries to developing countries	1.62	1	0.696	0.891
Insufficient incentivisation to producers to apply food safety measures	1.63	1	0.735	0.857
Duplication of effort	1.66	1	0.729	0.905
Economic recession	1.71	1	0.756	0.939
Few skilled professionals in food safety	1.8	1	0.844	0.948
Use of different assessment methods	1.72	1	0.7	1.029
Food safety infrastructure	1.78	1	0.805	0.969
Political will	1.72	1	0.727	0.990
Insufficient enforcement of food safety measures	2.06	1	0.838	1.265
Lack of responsible food safety agency	2.14	1	0.856	1.332
Existing food safety risk: International barriers to mitigation				
Barriers	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-score**
Lack of harmonization of regulations between countries	1.32	1	0.594	0.539
Economic pressures on the production chain	1.3	1	0.501	0.599
Data sharing between institutions	1.4	1	0.628	0.637
Poor communication between different	1.35	1	0.535	0.654

actors in the food chain				
Insufficient knowledge transfer from affluent countries to developing countries	1.42	1	0.615	0.683
Lack of resources of funding organizations	1.44	1	0.634	0.694
Economic recession	1.42	1	0.568	0.739
Lack of enforceable regulations	1.48	1	0.636	0.755
Political will	1.58	1	0.72	0.806
Use of different assessment methods	1.52	1	0.621	0.837
Food safety infrastructure	1.58	1	0.661	0.877
Insufficient incentivisation to producers to apply food safety measures	1.55	1	0.619	0.889
Lack of responsible food safety agency	1.7	1	0.74	0.946
Duplication of effort	1.64	1	0.62	1.032
Few skilled professionals in food safety	1.76	1	0.724	1.050
Insufficient enforcement of food safety measures	1.84	1	0.789	1.065
Emerging food safety risk: National barriers to mitigation				
Barriers	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-score**
Lack of resources of funding organizations	1.36	1	0.635	0.567
Data sharing between institutions	1.39	1	0.626	0.623
Lack of harmonization of regulations between countries	1.42	1	0.63	0.667
Insufficient incentivisation to producers to apply food safety measures	1.47	1	0.693	0.678
Economic pressures on the production chain	1.43	1	0.602	0.714
Poor communication between different actors in the food chain	1.42	1	0.585	0.718
Lack of enforceable regulations	1.65	1	0.793	0.820
Insufficient knowledge transfer from affluent countries to developing countries	1.6	1	0.686	0.875
Political will	1.63	1	0.708	0.890
Economic recession	1.61	1	0.67	0.910

Few skilled professionals in food safety	1.74	1	0.808	0.916
Food safety infrastructure	1.74	1	0.796	0.930
Duplication of effort	1.66	1	0.689	0.958
Use of different assessment methods	1.7	1	0.692	1.012
Insufficient enforcement of food safety measures	1.91	1	0.823	1.106
Lack of responsible food safety agency	1.97	1	0.667	1.454
Emerging food safety risk: International barriers to mitigation				
Barriers	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-Score**
Lack of harmonization of regulations between countries	1.35	1	0.633	0.553
Data sharing between institutions	1.4	1	0.612	0.654
Lack of resources of funding organizations	1.41	1	0.614	0.668
Insufficient incentivisation to producers to apply food safety measures	1.41	1	0.614	0.668
Poor communication between different actors in the food chain	1.35	1	0.517	0.677
Food safety infrastructure	1.49	1	0.68	0.721
Insufficient knowledge transfer from affluent countries to developing countries	1.46	1	0.62	0.742
Economic pressures on the production chain	1.41	1	0.548	0.748
Lack of enforceable regulations	1.52	1	0.651	0.799
Use of different assessment methods	1.54	1	0.62	0.871
Economic recession	1.5	1	0.59	0.847
Political will	1.6	1	0.672	0.893
Few skilled professionals in food safety	1.64	1	0.706	0.907
Insufficient enforcement of food safety measures	1.76	1	0.737	1.031
Duplication of effort	1.67	1	0.628	1.067
Lack of responsible food safety agency	1.79	1	0.74	1.068

Table 7: Gaps in current food safety research regarding the mitigation of existing and emerging food safety risks nationally and internationally

Gaps in current food safety rresearch rregarding the mmitigation of eexisting ffood ssafety risks: Nationally				
Research gap	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-Score**
Monitoring programs	1.37	1	0.662	0.559
Interactions between different drivers	1.31	1	0.523	0.593
Research encompassing the whole food chain	1.37	1	0.607	0.610
Developing methods to integrate interdisciplinary research	1.35	1	0.57	0.614
New detection methods	1.42	1	0.661	0.635
Understanding the effects of drivers on food safety risks	1.44	1	0.691	0.637
Understanding economic impacts of food risks	1.51	1	0.68	0.750
Methods of risk assessment	1.51	1	0.665	0.767
Understanding effective risk governance	1.56	1	0.718	0.780
Trend analysis	1.58	1	0.743	0.781
Gaps in current risk assessment methods regarding what is assessed	1.51	1	0.651	0.783
Predictive methodologies	1.56	1	0.705	0.794
Understanding the social impacts of food risks	1.56	1	0.667	0.840
Research into the impact of consumer behavior	1.57	1	0.676	0.843
New horizon scanning methods	1.58	1	0.661	0.877
Uncertainty reduction in risk models	1.52	1	0.589	0.883
Effective risk ranking methodologies	1.54	1	0.604	0.894
Understanding risk-benefit tradeoffs	1.54	1	0.604	0.894
Use of HALYS (Health Adjusted life years e.g. Qalys)	1.65	1	0.618	1.052
Gaps in ccurrent ffood ssafety rresearch rregarding the mmitigation of eexisting ffood ssafety rrisks: Internationally				
Research Gap	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-Score**
Research encompassing the whole food chain	1.34	1	0.584	0.582
Understanding the effects of drivers on food safety risks	1.37	1	0.607	0.610
Monitoring programs	1.35	1	0.568	0.616
Understanding the social impacts of food risks	1.43	1	0.648	0.664

Developing methods to integrate interdisciplinary research	1.39	1	0.562	0.694
Detection methods	1.39	1	0.562	0.694
Understanding economic impacts of food risks	1.44	1	0.634	0.694
Interactions between different drivers	1.43	1	0.618	0.696
Trend analysis	1.54	1	0.706	0.765
New horizon scanning methods	1.47	1	0.605	0.777
Understanding effective risk governance	1.51	1	0.636	0.802
Gaps in current risk assessment methods regarding what is assessed	1.49	1	0.605	0.810
Understanding risk-benefit tradeoffs	1.56	1	0.649	0.863
Methods of risk assessment	1.56	1	0.649	0.863
Predictive methodologies	1.6	1	0.686	0.875
Research into the impact of consumer behavior	1.55	1	0.619	0.889
Uncertainty reduction in risk models	1.58	1	0.615	0.943
Effective risk ranking methodologies	1.63	1	0.637	0.989
Use of HALYS (Health Adjusted life years e.g. Qalys)	1.68	1	0.628	1.083
Gaps in current ffood ssafety rresearch rregarding the mmitigation of emerging ffood ssafety rrisks: Nationally				
Research Gap	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-score**
New detection methods	1.25	1	0.536	0.466
Research encompassing the whole food chain	1.29	1	0.568	0.511
Monitoring programs	1.35	1	0.618	0.566
Understanding the effects of drivers on food safety risks	1.34	1	0.567	0.600
Developing methods to integrate interdisciplinary research	1.32	1	0.526	0.608
Interactions between different drivers	1.35	1	0.57	0.614
New horizon scanning methods	1.36	1	0.572	0.629
Research into the impact of consumer behavior	1.42	1	0.616	0.682
Gaps in current risk assessment methods regarding what is assessed	1.48	1	0.665	0.722
Predictive methodologies	1.47	1	0.65	0.723
Understanding risk-benefit tradeoffs	1.45	1	0.604	0.745
Methods of risk assessment	1.5	1	0.651	0.768

Understanding economic impacts of food risks	1.5	1	0.651	0.768
Trend analysis	1.53	1	0.679	0.781
Effective risk ranking methodologies	1.53	1	0.679	0.781
Understanding effective risk governance	1.53	1	0.665	0.797
Understanding the social impacts of food risks	1.5	1	0.652	0.767
Uncertainty reduction in risk models	1.55	1	0.619	0.889
Use of HALYS (Health Adjusted life years e.g. Qalys)	1.62	1	0.624	0.994
Gaps in current food safety research regarding the mitigation of emerging food safety risks: Internationally				
Research gap	$\bar{x}$	**Mean**	**Std. Deviation**	**Z-Score**
Research encompassing the whole food chain	1.32	1	0.578	0.554
New detection methods	1.35	1	0.618	0.566
Understanding the effects of drivers on food safety risks	1.41	1	0.629	0.652
Monitoring programs	1.42	1	0.632	0.665
Understanding the social impacts of food	1.42	1	0.632	0.665
Developing methods to integrate interdisciplinary research	1.39	1	0.562	0.694
New horizon scanning methods	1.4	1	0.564	0.709
Interactions between different drivers risks	1.44	1	0.587	0.750
Understanding risk-benefit tradeoffs	1.49	1	0.621	0.789
Understanding risk-benefit tradeoffs	1.49	1	0.621	0.789
Research into the impact of consumer behavior	1.52	1	0.651	0.799
Trend analysis	1.54	1	0.664	0.813
Understanding effective risk governance	1.53	1	0.65	0.815
Understanding economic impacts of food risks	1.51	1	0.621	0.821
Gaps in current risk assessment methods regarding what is assessed	1.55	1	0.664	0.828
Methods of risk assessment	1.6	1	0.686	0.875
Predictive methodologies	1.59	1	0.659	0.895
Effective risk ranking methodologies	1.66	1	0.675	0.978
Uncertainty reduction in risk models	1.65	1	0.648	1.003
Use of HALYS (Health Adjusted life years e.g. Qalys)	1.67	1	0.628	1.067

Table 8: Research finding and relevancy for policy translation

Research finding	Policy translation
Food legislation is frequently outdated, inadequate and fragmented. New legislation needs to be based on the best scientific evidence available.	National food safety policies need be a high priority for governments. If food safety problems are currently effectively being mitigated, resources are still required to mitigate potential emerging food safety risks. Policy "complacency" may be problematic and lead to difficulties in managing an unanticipated food safety crisis should one occur.
Specific drivers do not increase or decrease specific food safety risks. Rather each driver is associated with increasing or decreasing multiple food safety risks. Developing policies which influence a single driver in a single geographic location will have very little impact on food safety problems.	Adoption of a "systems" or holistic approach is needed. It is important to consider existing and emerging food safety risks as part of any policy portfolio.
Food safety policies require a foundation of evidence which simultaneously considers evidence originating in the social and natural science areas, and which can integrate quantitative and qualitative data.	Research funding and future research agendas must reflect this evidence requirement. Approaches such as Bayesian Network Analysis which can integrate disparate data sets may be required to deliver appropriate evidence.
Effective food safety risk management is contingent on "buy-in" from a range of actors in the food web, including consumers.	• Co-ordination of food safety activities at a national level should include all relevant stakeholders including ministries of health, agriculture, trade/industry, fisheries, tourism and others, as appropriate. • Information networks on food safety issues should work to build confidence among consumers and the media. • Training/education in food safety should be on-going and focused on government officials, industry leaders and consumers. Consumer awareness raising to encourage consumers to be quality and safety conscious.
The experts prioritized the need for national and international food safety agencies to be established where this has not already been done. The balance between supply, cost and environmental impact requires careful consideration to meet the challenge of provision of safe, nutritious food, while maintaining or enhancing ecosystem services.	Food safety directly contributes to food security. Agencies might be better placed to manage food (and nutrition) security through application of an integrated, coherent policy response, particularly at the international, intergovernmental agency level.
Given that the food system must be resilient to future shocks (whether these originate in the social or natural environment, and compromise safety or other aspects of food security), and that these system shocks are partly unpredictable in terms of their when and where they will occur, a portfolio policy response is needed. This will enable flexible responses to predictable, but uncertain, future events.	A portfolio of policy responses is required to ensure rapid responses can be activated in response to emerging food safety emergencies. It may be most practical for these to be curated by international or regional food security agencies.
There is a need for further capacity building to improve national risk assessment in less affluent countries. At the same time, international requirements focus on increasing capacity to facilitate global harmonization of food safety policy. Global food safety goals can only be achieved if there is sufficient investment in capacity to implement food safety activities and regulations in developing nations. Increased investment will increase capacity and standards in less affluent countries. This will require further national and regional investment, and militates against the principle of "business as usual".	Increased investment in capacity building in Low and Middle Income Countries (LMICs) will enable effective assessment, mitigation of, and communication about, food safety issues. Careful assessment of local requirements will ensure the most efficient allocation of resources.

Figure 1

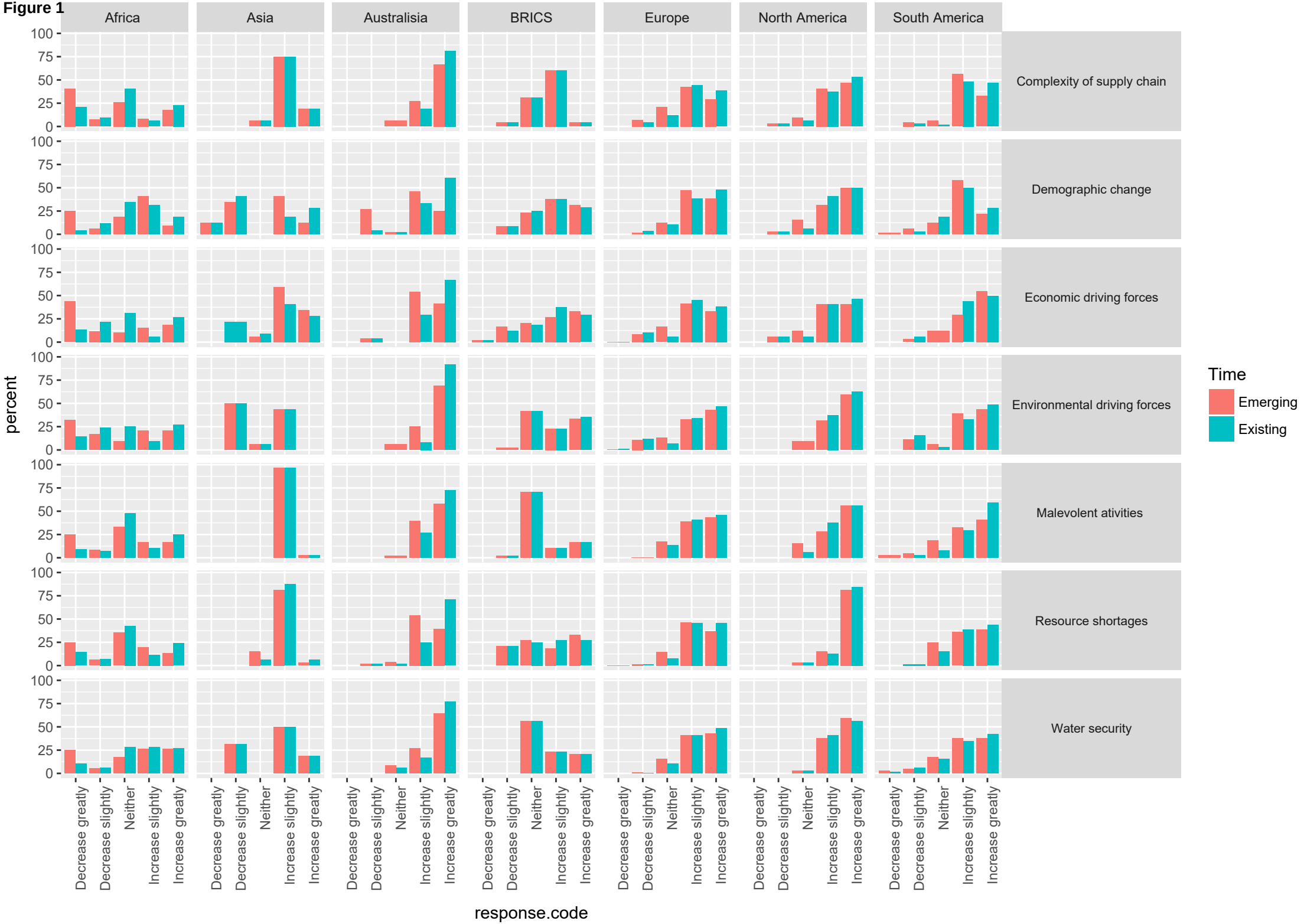
Africa
Asia
Australisia
BRICS
Europe
North America
South America
Complexity of supply chain
Demographic change
Economic driving forces
Environmental driving forces
Malevolent ativities
Resource shortages
Water security
percent
100
75
50
25
0
Decrease greatly
Decrease slightly
Neither
Increase slightly
Increase greatly
response.code
Time
Emerging
Existing

Figure 2


Complexity of supply chain
Demographic change
Economic driving forces
Environmental driving forces
Malevolent ativities
Resource shortages
Water security
Antibiotic resistance
Consumer behaviours
Effects of GM
Effects of nanotech
Effects of new technologies
Growth hormones
Microbiological
Pesticide residues
Plant diseases
Plant pests
Pollutants
Radioactive contamination
Toxicological Biological
Toxicological Chemical
Veterinary drug residues
Zoonoses
count
0
15
30
Decrease greatly
Decrease slightly
Neither
Increase slightly
Increase greatly
Time
Emerging
Existing

Annex 1

Annex 1: Regression coefficients for the determinants of existing food safety risks. Model selection retained the variables driver, region, area of expertise, age and gender.

Existing	Estimate	Std. Error	z value	Pr(>|z|)
Decrease slightly((Intercept))	0.45	0.76	0.59	0.55
Decrease slightly(Age)	0.11	0.13	0.89	0.37
Decrease slightly(ContinentAsia)	1.53	0.58	2.62	*0.01*
Decrease slightly(ContinentAustralasia)	0.38	0.57	0.67	0.50
Decrease slightly(ContinentBRICS)	-0.47	0.40	1.17	0.24
Decrease slightly(ContinentEurope)	0.79	0.37	2.13	*0.03*
Decrease slightly(ContinentMiddle East)	12.40	0.51	24.46	*< 2e-16*
Decrease slightly(ContinentNorth America)	2.74	1.08	2.55	*0.01*
Decrease slightly(ContinentSouth America)	1.08	0.66	1.64	0.10
Decrease slightly(DriverConsumer priorities)	-0.39	0.71	0.55	0.58
Decrease slightly(DriverDemographic change)	-1.12	0.83	1.35	0.18
Decrease slightly(DriverEconomic driving forces)	-0.22	0.77	0.29	0.77
Decrease slightly(DriverEnvironmental drivers)	-0.38	0.77	0.49	0.63
Decrease slightly(DriverGeopolitical forces)	0.32	0.77	0.41	0.68
Decrease slightly(DriverMalevolent activities)	-1.15	0.83	1.39	0.17
Decrease slightly(DriverMedia representation)	-0.04	0.71	0.06	0.95
Decrease slightly(DriverPolitical will)	-0.78	0.68	1.14	0.25
Decrease slightly(DriverResource shortages)	-1.85	0.85	2.16	*0.03*
Decrease slightly(DriverSocietal values)	-0.21	0.70	0.30	0.76
Decrease slightly(DriverTechnological changes)	0.06	0.68	0.09	0.93
Decrease slightly(DriverWater security)	-2.10	0.73	2.87	*0.00*
Decrease slightly(GenderMale)	0.07	0.28	0.25	0.80
Increase greatly((Intercept))	1.60	0.74	2.16	*0.03*
Increase greatly(Age)	0.16	0.12	1.26	0.21
Increase greatly(ContinentAsia)	0.84	0.57	1.49	0.14

Increase greatly(ContinentAustralasia)	-0.17	0.56	0.31	0.75
Increase greatly(ContinentBRICS)	-1.52	0.40	3.81	*0.00*
Increase greatly(ContinentEurope)	0.49	0.35	1.41	0.16
Increase greatly(ContinentMiddle East)	13.06	0.42	31.42	*< 2e-16*
Increase greatly(ContinentNorth America)	2.27	1.07	2.13	*0.03*
Increase greatly(ContinentSouth America)	1.15	0.63	1.83	0.07
Increase greatly(DriverConsumer priorities)	-1.54	0.69	2.23	*0.03*
Increase greatly(DriverDemographic change)	-0.35	0.72	0.49	0.62
Increase greatly(DriverEconomic driving forces)	-0.58	0.73	0.79	0.43
Increase greatly(DriverEnvironmental drivers)	-0.26	0.72	0.37	0.71
Increase greatly(DriverGeopolitical forces)	-2.02	0.85	2.38	*0.02*
Increase greatly(DriverMalevolent activities)	-0.40	0.72	0.55	0.58
Increase greatly(DriverMedia representation)	-1.74	0.71	2.45	*0.01*
Increase greatly(DriverPolitical will)	-2.01	0.67	2.98	*0.00*
Increase greatly(DriverResource shortages)	-0.28	0.69	0.41	0.68
Increase greatly(DriverSocietal values)	-1.92	0.71	2.71	*0.01*
Increase greatly(DriverTechnological changes)	-1.84	0.69	2.67	*0.01*
Increase greatly(DriverWater security)	-1.39	0.63	2.19	*0.03*
Increase greatly(GenderMale)	0.01	0.27	0.04	0.97
Increase slightly((Intercept))	0.82	0.83	1.00	0.32
Increase slightly(Age)	0.28	0.12	2.37	*0.02*
Increase slightly(ContinentAsia)	1.42	0.57	2.48	*0.01*
Increase slightly(ContinentAustralasia)	1.11	0.56	1.96	*0.05*
Increase slightly(ContinentBRICS)	-1.76	0.45	3.96	*0.00*
Increase slightly(ContinentEurope)	1.45	0.36	3.98	*0.00*
Increase slightly(ContinentMiddle East)	12.70	0.47	26.95	*< 2e-16*
Increase slightly(ContinentNorth America)	3.52	1.07	3.30	*0.00*
Increase slightly(ContinentSouth America)	1.70	0.65	2.64	*0.01*
Increase slightly(DriverConsumer priorities)	-1.42	0.67	2.13	*0.03*
Increase slightly(DriverDemographic change)	-0.52	0.71	0.72	0.47

Increase slightly(DriverEconomic driving forces)	-0.51	0.71	0.71	0.48
Increase slightly(DriverEnvironmental drivers)	-0.67	0.71	0.93	0.35
Increase slightly(DriverGeopolitical forces)	-0.75	0.74	1.01	0.31
Increase slightly(DriverMalevolent activities)	-0.97	0.72	1.35	0.18
Increase slightly(DriverMedia representation)	-1.88	0.69	2.74	*0.01*
Increase slightly(DriverPolitical will)	-2.20	0.65	3.37	*0.00*
Increase slightly(DriverResource shortages)	-0.94	0.69	1.37	0.17
Increase slightly(DriverSocietal values)	-1.70	0.67	2.53	*0.01*
Increase slightly(DriverTechnological changes)	-2.01	0.67	3.02	*0.00*
Increase slightly(DriverWater security)	-2.16	0.63	3.42	*0.00*
Increase slightly(GenderMale)	0.56	0.27	2.10	*0.04*
Neither decrease or increase((Intercept))	0.25	0.76	0.33	0.74
Neither decrease or increase(Age)	0.11	0.13	0.90	0.37
Neither decrease or increase(ContinentAsia)	1.28	0.60	2.15	*0.03*
Neither decrease or increase(ContinentAustralasia)	0.81	0.56	1.44	0.15
Neither decrease or increase(ContinentBRICS)	-1.04	0.44	2.37	*0.02*
Neither decrease or increase(ContinentEurope)	1.25	0.38	3.34	*0.00*
Neither decrease or increase(ContinentMiddle East)	11.74	0.62	19.09	*< 2e-16*
Neither decrease or increase(ContinentNorth America)	3.11	1.08	2.89	*0.00*
Neither decrease or increase(ContinentSouth America)	1.47	0.65	2.25	*0.02*
Neither decrease or increase(DriverConsumer priorities)	-0.70	0.72	0.98	0.33
Neither decrease or increase(DriverDemographic change)	-0.05	0.76	0.06	0.95
Neither decrease or increase(DriverEconomic driving forces)	-0.46	0.78	0.59	0.56
Neither decrease or increase(DriverEnvironmental drivers)	-0.56	0.78	0.71	0.48
Neither decrease or increase(DriverGeopolitical forces)	0.84	0.77	1.10	0.27
Neither decrease or increase(DriverMalevolent activities)	0.49	0.75	0.65	0.51
Neither decrease or increase(DriverMedia representation)	-0.11	0.71	0.16	0.88
Neither decrease or increase(DriverPolitical will)	-0.76	0.68	1.11	0.27
Neither decrease or increase(DriverResource shortages)	-1.25	0.78	1.60	0.11
Neither decrease or increase(DriverSocietal values)	-0.38	0.71	0.54	0.59

Neither decrease or increase(DriverTechnological changes)	-1.27	0.73	1.74	0.08
Neither decrease or increase(DriverWater security)	-2.38	0.75	3.18	*0.00*
Neither decrease or increase(GenderMale)	0.23	0.28	0.84	0.40

Annex 2

Annex 2: Regression coefficients for the determinants of emerging food safety risks. Model selection retained the variables driver, region, area of expertise, age and gender.

Emerging	Estimate	Std. Error	z value	Pr(>|z|)
Decrease slightly((Intercept))	0.52	0.91	0.58	0.57
Decrease slightly(Age)	0.13	0.15	0.87	0.38
Decrease slightly(ContinentAsia)	-0.11	0.56	0.19	0.85
Decrease slightly(ContinentAustralasia)	14.74	0.28	51.81	*< 2e-16*
Decrease slightly(ContinentBRICS)	-0.88	0.46	1.89	0.06
Decrease slightly(ContinentEurope)	0.33	0.45	0.74	0.46
Decrease slightly(ContinentMiddle East)	12.04	0.55	21.76	*< 2e-16*
Decrease slightly(ContinentNorth America)	14.54	0.27	53.36	*< 2e-16*
Decrease slightly(ContinentSouth America)	0.76	0.86	0.88	0.38
Decrease slightly(DriverConsumer priorities)	0.50	0.84	0.60	0.55
Decrease slightly(DriverDemographic change)	-0.43	0.92	0.47	0.64
Decrease slightly(DriverEconomic driving forces)	0.06	0.85	0.07	0.95
Decrease slightly(DriverEnvironmental drivers)	-0.45	0.88	0.52	0.60
Decrease slightly(DriverGeopolitical forces)	1.29	1.01	1.28	0.20
Decrease slightly(DriverMalevolent activities)	-0.67	0.89	0.76	0.45
Decrease slightly(DriverMedia representation)	0.22	0.82	0.27	0.79
Decrease slightly(DriverPolitical will)	0.29	0.82	0.36	0.72
Decrease slightly(DriverResource shortages)	-1.55	0.94	1.65	0.10
Decrease slightly(DriverSocietal values)	-0.05	0.79	0.06	0.95
Decrease slightly(DriverTechnological changes)	-0.18	0.76	0.24	0.81
Decrease slightly(DriverWater security)	-0.83	0.84	0.99	0.32
Decrease slightly(GenderMale)	0.35	0.33	1.06	0.29
Increase greatly((Intercept))	0.63	0.89	0.71	0.48
Increase greatly(Age)	0.45	0.15	2.97	*0.00*
Increase greatly(ContinentAsia)	-0.04	0.56	0.08	0.94
Increase greatly(ContinentAustralasia)	13.97	0.29	48.99	*< 2e-16*
Increase greatly(ContinentBRICS)	-1.84	0.50	3.68	*0.00*

Increase greatly(ContinentEurope)	-0.11	0.45	0.24	0.81
Increase greatly(ContinentMiddle East)	12.08	0.51	23.78	*< 2e-16*
Increase greatly(ContinentNorth America)	14.14	0.27	53.01	*< 2e-16*
Increase greatly(ContinentSouth America)	0.71	0.86	0.82	0.41
Increase greatly(DriverConsumer priorities)	-1.34	0.86	1.56	0.12
Increase greatly(DriverDemographic change)	0.22	0.85	0.26	0.80
Increase greatly(DriverEconomic driving forces)	-0.71	0.83	0.86	0.39
Increase greatly(DriverEnvironmental drivers)	-0.38	0.82	0.46	0.64
Increase greatly(DriverGeopolitical forces)	-2.66	1.39	1.91	0.06
Increase greatly(DriverMalevolent activities)	-0.21	0.82	0.26	0.80
Increase greatly(DriverMedia representation)	-1.67	0.84	1.98	0.05
Increase greatly(DriverPolitical will)	-1.80	0.85	2.11	*0.03*
Increase greatly(DriverResource shortages)	-0.15	0.79	0.19	0.85
Increase greatly(DriverSocietal values)	-2.80	0.90	3.12	*0.00*
Increase greatly(DriverTechnological changes)	-2.51	0.79	3.17	*0.00*
Increase greatly(DriverWater security)	-0.50	0.78	0.64	0.52
Increase greatly(GenderMale)	0.09	0.33	0.29	0.78
Increase slightly((Intercept))	1.08	0.86	1.25	0.21
Increase slightly(Age)	0.37	0.14	2.63	0.01
Increase slightly(ContinentAsia)	-0.23	0.54	0.43	0.67
Increase slightly(ContinentAustralasia)	14.63	0.24	60.17	*< 2e-16*
Increase slightly(ContinentBRICS)	-2.10	0.48	4.36	*0.00*
Increase slightly(ContinentEurope)	0.66	0.43	1.55	0.12
Increase slightly(ContinentMiddle East)	13.08	0.40	32.93	*< 2e-16*
Increase slightly(ContinentNorth America)	14.83	0.22	68.74	*< 2e-16*
Increase slightly(ContinentSouth America)	1.23	0.83	1.48	0.14
Increase slightly(DriverConsumer priorities)	-0.92	0.80	1.16	0.25
Increase slightly(DriverDemographic change)	-0.37	0.83	0.45	0.65
Increase slightly(DriverEconomic driving forces)	-0.54	0.79	0.68	0.50
Increase slightly(DriverEnvironmental drivers)	-0.65	0.80	0.82	0.41

Increase slightly(DriverGeopolitical forces)	-0.07	0.97	0.08	0.94
Increase slightly(DriverMalevolent activities)	-0.72	0.80	0.90	0.37
Increase slightly(DriverMedia representation)	-1.68	0.79	2.13	*0.03*
Increase slightly(DriverPolitical will)	-1.64	0.79	2.09	*0.04*
Increase slightly(DriverResource shortages)	-0.85	0.78	1.09	0.27
Increase slightly(DriverSocietal values)	-1.84	0.76	2.43	*0.02*
Increase slightly(DriverTechnological changes)	-2.50	0.73	3.42	*0.00*
Increase slightly(DriverWater security)	-1.10	0.76	1.45	0.15
Increase slightly(GenderMale)	0.61	0.31	1.93	0.05
Neither decrease or increase((Intercept))	1.21	0.88	1.37	0.17
Neither decrease or increase(Age)	0.12	0.14	0.84	0.40
Neither decrease or increase(ContinentAsia)	-0.09	0.56	0.17	0.87
Neither decrease or increase(ContinentAustralasia)	14.89	0.27	54.45	*< 2e-16*
Neither decrease or increase(ContinentBRICS)	-1.78	0.49	3.60	*0.00*
Neither decrease or increase(ContinentEurope)	0.99	0.44	2.24	*0.02*
Neither decrease or increase(ContinentMiddle East)	11.52	0.63	18.38	*< 2e-16*
Neither decrease or increase(ContinentNorth America)	15.20	0.24	63.66	*< 2e-16*
Neither decrease or increase(ContinentSouth America)	1.27	0.85	1.50	0.13
Neither decrease or increase(DriverConsumer priorities)	-0.81	0.81	0.99	0.32
Neither decrease or increase(DriverDemographic change)	-0.87	0.86	1.01	0.31
Neither decrease or increase(DriverEconomic driving forces)	-1.21	0.83	1.46	0.15
Neither decrease or increase(DriverEnvironmental drivers)	-0.75	0.82	0.92	0.36
Neither decrease or increase(DriverGeopolitical forces)	0.90	0.97	0.92	0.36
Neither decrease or increase(DriverMalevolent activities)	-0.70	0.82	0.86	0.39
Neither decrease or increase(DriverMedia representation)	-0.45	0.78	0.58	0.56
Neither decrease or increase(DriverPolitical will)	-0.51	0.78	0.65	0.52
Neither decrease or increase(DriverResource shortages)	-1.18	0.80	1.47	0.14
Neither decrease or increase(DriverSocietal values)	-0.82	0.76	1.08	0.28
Neither decrease or increase(DriverTechnological changes)	-1.96	0.74	2.65	*0.01*
Neither decrease or increase(DriverWater security)	-1.52	0.79	1.91	0.06

Neither decrease or increase(GenderMale)	0.65	0.32	2.04	*0.04*

Highlights

Expert elicitation *via* Dephi of the drivers of existing and emerging food safety risks

Single drivers had multiple impacts upon food safety risks

Involving a range of stakeholders in the policy development process is important

A holistic or systems approach to the mitigation of food safety risks is required