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Extrapolating understanding of food risk perceptions to emerging food safety cases

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Important determinants of risk perceptions associated with foods are the extent to which the potential hazards are perceived to have *technological* or *naturally occurring* origins, together with the acute vs. chronic dimension in which the potential hazard is presented (*acute* or *chronic*). This study presents a case study analysis based on an extensive literature review examining how these hazard characteristics affect people's risk and benefit perceptions, and associated attitudes and behaviors. The cases include *E. coli* incidences (outbreaks linked to fresh spinach and fenugreek sprouts), contamination of fish by environmental pollutants, (organochlorine contaminants in farmed salmon), radioactive contamination of food following a nuclear accident (the Fukushima accident in Japan), and GM salmon destined for the human food chain. The analysis of the cases over the acute vs. chronic dimension suggests that longitudinal quantification of the relationship between risk perceptions and impacts is important for both acute and chronic food safety, but this has infrequently been applied to chronic hazards. Technologies applied to food production tend to potentially be associated with higher levels of risk perception, linked to perceptions that the risk is unnatural. However, for some risks (e.g. those involving biological irreversibility), moral or ethical concerns may be more important determinants of consumer responses than risk or benefit perceptions. (Lack of) trust has been highlighted in all of the cases suggesting transparent and honest risk–benefit communications following the occurrence of a food safety incident. Implications for optimizing associated risk communication strategies, additional research linking risk perception, and other quantitative measures, including comparisons in time and space, are suggested.

Keywords: Food risk; risk perception; benefit perception; risk communication, food safety

1. Introduction

It has been established that people's responses to different risks are affected by how they perceive potential hazard characteristics. Furthermore people's risk perceptions do not always align with technical risk estimates provided by experts (Fischhoff et al. 1978; Slovic 2000). People's risk perceptions are often reasonable but can also militate against adoption of self protective behaviors, implying that effective risk communication may be required (Fischhoff and Kadvany 2011). In the context of public health, effective risk communication aims to provide laypeople with the

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information they need to make informed, independent judgments (Morgan et al. 2002). Food safety is of particular interest in this context, as there is some evidence suggesting that food risks are perceived differently from non-food risks (FAO/WHO, forthcoming). This is because complete avoidance of food risks is not possible, and because food has *cultural, symbolic, familial,* and *religious* connotations which must be taken into account when developing risk messages (Frewer et al. 2015). In addition, food may simultaneously be associated with risks, such as inclusion of contaminants, and benefits, such as nutritional advantages (Cohen et al. 2005; Hoekstra et al. 2013a, 2013b; van der Voet, de Mul, and van Klaveren 2007) suggesting that both risk and benefit perceptions associated with foods need to be considered when developing risk communication strategies (van Dijk, Fischer, and Frewer 2011; Hooper 2006; Saba and Messina 2003).

Some types of determinants of risk perceptions seem to be specifically important in shaping people's responses to food risks such as the extent to which the potential hazards are perceived to have 'technological' or 'naturally occurring' origins (Frewer et al. 2013b; Rozin et al. 2004; Siegrist 2008). The application of technologies to food production may be perceived as hazardous. Failing to take account of this negative starting point, and subsequent negligence of the needs and priorities of consumers during the process of technology development and implementation, has resulted in societal rejection of potentially useful emerging food technologies such as genetically modified (GM) foods (Frewer et al. 2011; Raley et al. 2016). In contrast, consumers' low levels of risk perceptions associated with naturally occurring food hazards has increased their tendency to adopt potentially risk behaviors, for example in relation to food preparation practices (Nauta et al. 2008).

Further complexity is provided by the acute vs. chronic context in which the potential hazard is presented (Glik 2007). Presenting a naturally occurring risk in an acute or 'crisis' context may increase risk perceptions (Pidgeon, Kasperson, and Slovic 2003). Examples include foodborne outbreaks that may be difficult to predict in terms of which microbial hazard will occur when, and affect whom. In the case of chronically occurring food hazards, (e.g. radioactive contamination of food), more information regarding the potential for varied impacts across differentially vulnerable populations may become available as a consequence of the ongoing risk assessment process (WHO/FAO, forthcoming). The acute vs. chronic context of the hazard may differentially influence people's perceptions of risks, and hence their behaviors. In order to understand the potential impacts of both acute and chronic food safety incidents on both public health and economic functioning of the food chain, it is important to quantify the relationships between food risk perceptions and impacts. However, new metrics may be needed to assess this relationship (Dreyer et al. 2010), which can be formally included in the risk assessment phase of the risk analysis process.

This paper presents case study analyses based on an extensive literature review examining how food hazard characteristics affect people's risk and benefit perceptions, and associated attitudes and behaviors. Two 'axes' frame the analysis. The first relates to the 'risk origin' (technological or natural). The second relates to the 'acute vs. chronic dimension' of the food hazard. Therefore, the following hypotheses will be tested through case study analysis:

H1: Consumers perceive the application of technologies to food production as hazardous.

H2: Consumers' risk perceptions of naturally occurring food hazards may have negative impacts regarding optimizing nutrition.

H3: Acute vs. chronic hazards differentially influence people's risk perceptions and behaviors due to the temporal context

2. Methodology

Use of case studies to understand a specific research question is a research strategy that focuses on understanding the dynamics present within a single or multiple settings (Eisenhardt 1989). In the comparative analysis of cases that follows, four food-related cases were presented. In each case, it is arguable that there is potential for risk perceptions associated with the food hazard to lead consumers to behave in a way contrary to their own, and societal interests, where societal is understood to refer to a 'common good.' Thus, it should be possible to derive *generic*, as well as *situation specific*, conclusions regarding risk perception and food choice. The cases selected have been subject to considerable attention among different stakeholders (e.g. the scientific community in general, regulatory agencies, media, and representatives of civic society such as non-governmental organizations). The cases include *E. coli* incidences, (outbreaks linked to fresh spinach and fenugreek sprouts), contamination of fish by environmental pollutants, (organochlorine contaminants in farmed salmon), radioactive contamination of food following a nuclear accident (the accident at the Fukushima Dai-ichi nuclear power plant), and genetically modified (GM) salmon destined for the human food chain.

Classification of the cases according to risk origin and acute vs. chronic dimension is provided in Table 1.

Each case is described with a brief explanation about the risk issue, information about the factors linked to increased consumer risk perceptions, the impact of the incident, a chronological overview from consumers' perspective, and where feasible, research reporting consumers' attitudes and behavior during and/or after the incidents, and, if applicable, discussion of the additional metrics needed to quantify the relationship between risk perceptions and impacts.

Table 1. Classification of the cases according to risk origin (technological vs. natural) and acute vs. chronic dimension.

Case	Technological vs. natural	Acute vs. chronic
• *E. coli* 0157:H7 outbreak linked to fresh spinach (USA, September 2006) • *E.coli* outbreak linked to fenugreek sprouts (Germany, May-June 2011)	Natural	Acute
• Organochlorine contaminants in farmed Atlantic salmon (United Kingdom, January 2004)	Technological	Chronic presented in a crisis context
• The accident at the Fukushima Dai-ichi nuclear power plant (Japan, March 2011)	Technological	Acute and chronic
• GM salmon destined for the human food chain	Technological	Chronic

Table 2. Overview of English language media reporting on the four cases in this paper.

Incident Timeline \First report	Science reports Organochloride in Farmed Salmon January 2004	*E. coli* 0157:H7 in fresh Spinach September 2006	Fukushima nuclear power plant accident March 2011	*E. coli* 0104: H4 in fenugreek sprouts May 2011
2004	3 reports (January)			
2005	1 report (October)			
2006		16 reports (8 in September, 6 in October, 1 in November, 1 in December)		
2007		1 report (March)		
2008	1 report (January)	4 reports (March, June, July, September)		
2009		1 report (June)		
2010				
2011			3 reports (April, August, October)	5 reports (June)
2012			1 report (October)	
2013			1 report (May)	
2014			3 reports (2 in May, 1 in August)	
2015			13 reports (1 in January, 9 in February (associated with Japan visit prince William), 3 in April)	
Total	5	22	21	5
Search term	Organochloride Farmed	Coli Spinach	Fukushima Food	Coli Sprouts

Note: All search conducted for reports following first incident in LexisNexis academic power search using Major US and world news as sources on 17-June-2016.

The number of English language media reports that were published about each case are provided in Table 2. Although not having access to media reports in other languages (e.g. German, Japanese) is a limitation to reflect the complete picture on the information that those consumers received, Table 2 may still be a good proxy reflecting societal interests or social amplification of risk effect.

3. Case studies

3.1. E. coli *incidences*

Some strains of *E. coli* bacteria (e.g. Shiga Toxin producing *E. coli* (STEC) such as *E. coli* 0157:H7, *E. coli* O104:H4) are pathogenic, resulting in diarrhea or serious conditions (e.g. hemolytic uremic syndrome (HUS)) that can be fatal (UK Food Standards Agency 2013). STEC are among the most reported and monitored food pathogens in the EU and US because they frequently cause sporadic cases of illnesses and large foodborne outbreaks in these countries (Centers for Disease Control and Prevention 2013; European Food Safety Authority 2013). When communicated in a 'crisis' context, *E. coli* outbreaks have the potential to generate high level of public concern (UK Food Standards Agency 2013).

Consumption of foods and food categories associated with the outbreak tends to decline during the course of the outbreak (Mazzocchi 2006; McCullough, Marsh, and Huffaker 2013; Oniki 2006). These effects are large enough to quantify the 'acute' impacts of a food safety incident by examination of product-specific sales data (Hooper 2006; Saba and Messina 2003). However, risk perceptions may have negative unintended consequences, such as not consuming the product or substitutes for a prolonged period after the crisis ends, in spite of their health benefits (Cuite et al., forthcoming). Such 'stigmatization' of foods may therefore have negative long-term health effects (Gregory, Slovic, and Flynn 1996). Against this, failure to communicate risks effectively may have negative consequences for health if people fail to adopt self-protective behaviors. For example, (SteelFisher et al. 2013) asked participants from different age groups about their self-protective behaviors with regard to a hypothetical foodborne outbreak and found that they were very likely to adopt a range of recommended protective behaviors (although this is less common among older than younger participants). However, consumer surveys that were conducted during/following actual outbreaks in the US have shown that 41% of consumers, who were aware of the recall, did not look for the recalled food in their homes (Hallman, Cuite, and Hooker 2009), and that only 35% stopped eating that food (Blendon et al. 2010)

E. coli incidences may also occur sporadically where the risk is more likely to be presented in a 'chronic' context, and in these cases risks may be perceived as relatively 'lower.' In these cases, people are much less motivated to change behaviors, including self-protective ones (Fischer, Frewer, and Nauta 2006). Underreporting of the illness has been reported as a significant problem (Kaptan and Fischhoff 2011) due to being unsure of the cause, not knowing who to contact, believing reporting would not be helpful, and being too ill (Arendt et al. 2013). It is therefore relevant to compare perceptions of *E. coli* incidences across 'acute' and 'chronic' contexts.

Acute E. coli 0157:H7 *outbreak linked to fresh spinach.* In September 2006, *E. coli* 0157:H7 infections associated with fresh spinach affected over 200 people in 26 North American states. More than 100 of these cases were hospitalized, and 31 developed a form of kidney failure (HUS) that resulted in three deaths (Centers for Disease Control and Prevention 2006; Gelting et al. 2011). The source of the outbreak was identified as the processing and packaging plant of Natural Selection Foods, LLC in San Juan Bautista, CA. The precise means by which the bacteria spread to the spinach remained unknown, but US public health agencies were able to make predictions based on field work (US Food and Drug Administration 2007).

Following the outbreak, the lettuce safety initiative that had been launched in 2006 was expanded to include spinach (US Food and Drug Administration 2013b). This initiative aimed to reduce public health risks by focusing on the product, agents and areas of greatest concern and to alert consumers early and respond rapidly in the event of an outbreak.

During the outbreak, US Food and Drug Administration's (FDA) first advice to consumers was not to eat bagged fresh spinach (US Food and Drug Administration 2006c). This was updated the next day to not to eat fresh spinach and fresh spinach containing products (US Food and Drug Administration 2006b). The advice was updated again to confirm that spinach grown in non-implicated areas was safe to consume (US Food and Drug Administration 2006a). One consequence of FDA's communication was that around 18% of American consumers surveyed reported that they had stopped buying other bagged vegetables (Cuite et al., forthcoming). Bagged spinach expenditures were still 10% down at the end of 2007. In addition, over a period of 68 weeks, retail expenditures decreased 20% for bagged spinach, 1% for unbagged spinach, and 1% for all leafy greens (Arnade, Calvin, and Kuchler 2009).

Acute E. coli O104:H4 *outbreak linked to fenugreek sprouts.* Over 3800 cases of E. *coli* O104:H4 infections were reported in Germany between May and June 2011. More than 800 of those developed HUS that resulted in 54 deaths (Frank et al. 2011; Werber et al. 2012). In addition, several cases were reported in 12 other European countries, as well as the US and Canada (Bloch, Felczykowska, and Nejman-Faleńczyk 2012). Fenugreek seeds imported from Egypt were the most likely common link between the outbreak in Germany and a related outbreak in France (European Food Safety Authority 2011). As a result, the European Commission temporarily banned the import of fenugreek and certain seeds from Egypt to the European Market on July 6 (European Commission 2011). The relative rarity of the bacterial strain, the associated serious health consequences, difficulties in tracing the bacteria back to the food source, and communication failures on the part of authorities resulted in global media attention.

The German public health authorities provided information about the outbreak initially on 24 May 2011, without a reference to the affected crop. Consumers were advised the next day to be careful when eating raw tomatoes, lettuce, and cucumbers, in particular in Northern Germany, as these vegetables were believed to be the potential causes of the outbreak. On 26 May, the German authorities announced that three cucumbers from Spain were identified as the potential cause of the outbreak. On 1 June, however, the Spanish cucumbers were cleared. Finally, on 10 June, consumers were advised not to eat raw sprouts as contaminated sprouts of a Lower Saxony producer were identified as the source of the outbreak. On 23 June, an international investigation concluded that fenugreek sprouts were the common link between the German outbreak and a related outbreak in France (Werber et al. 2012). On 5 July, consumers were informed that the outbreak had ended but were still advised not to eat raw sprouts.

Consumer advisories during the outbreak have been criticized in terms of implicating a broad scope of unaffected produce as potential sources (cucumbers, tomatoes, and lettuce while the actual source was fenugreek sprouts). Furthermore, foreign production (Spain) was implicated in the outbreak, whereas in reality the problem had domestic origins, thus misleading consumers (Poudelet 2012; WHO 2011). As a consequence, consumer demand for a range of fresh produce, in particular, produce grown locally and imported from Spain declined considerably (Anderson 2011; Exner 2011). For example, German institutional kitchens (e.g. Stuttgart's youth hostels) stopped serving fresh salad. As well as having potentially negative impacts on the nutritional quality of diets, the negative economic impacts on Spanish producers were severe, with concomitant impacts on the broader local communities (Anderson 2011).

In contrast to acute outbreaks, chronic *E. coli* incidents affecting only one or very few people occur relatively frequently (Tariq, Haagsma, and Havelaar 2011).

These incidents tend not to receive much media attention and are not the focus of acute risk communication, although the consequences for affected individuals can be as severe as those who were infected during an outbreak. Optimistic bias (where people do not perceive they are personally vulnerable to a specific food risk) appears to militate against the adoption of safe domestic food hygiene practices associated with the prevention of foodborne illness (Miles and Scaife 2003; Redmond and Griffith 2004; Verbeke et al. 2007). In addition, engaging in safe food preparation practices may be considered as too difficult or otherwise costly or inconvenient as the risks of public health problems linked to microbial contamination of food are perceived to be low (Fischer, Frewer, and Nauta 2006).

3.2. Contamination of fish by environmental pollutants

Seafood, in particular fish, is an important supplier of omega-3 fatty acids, and a significant source of protein, vitamins, and minerals that are essential to maintain good health. Research has suggested that fish consumption may contribute to prevention of certain illnesses such as cardiovascular disease (Kris-Etherton, Harris, and Appel 2003), and cancer (Norat et al. 2005), and is beneficial to fetal neurodevelopment (Nesheim and Yaktine 2007). Increased fish consumption is frequently targeted as a public health nutrition goal (Ruxton et al. 2004). However, fish is also associated with environmental contaminants such as methylmercury and organochlorine compounds (e.g. PCB). Methylmercury might have adverse effects on developing fetuses (Nesheim and Yaktine 2007), while PCB's might adversely affect liver, kidney, and central nervous system (Sirot, Leblanc, and Margaritis 2012). Vulnerabilities to risk also vary across the population (for example, pregnant women and immuno-compromised individuals are more at risk from negative effects), and it is important to examine risk–benefit perceptions across different population groups (van Dijk et al. 2012).

The source of contamination with methylmercury or organochloride in fish may be perceived as technological or at least unnatural in origin. Both negative and positive consequences of changes in fish consumption may be perceived to be delayed, as health impacts (both toxicity effects and positive effects of omega-3 consumption) are long term. Communicating risks and benefits of fish consumption presents a challenge for experts to target the information to the appropriate audience and to help differentially vulnerable consumers make informed decisions to optimize their own health protection (Engelberth et al. 2013; Verbeke et al. 2008).

There is some evidence to suggest that risk communication in this regard is successful. Studies assessing the effect of risk communication messages (e.g. FDA mercury advisories) on awareness and behavior of vulnerable consumer groups demonstrate that they are generally aware of the risks, and follow the recommendations related to amount and what type of fish to consume, however, particular attention is needed for less educated, less knowledgeable, and low-income groups (e.g. Driscoll, Sorensen, and Deerhake 2012; Lando, Fein, and Choinière 2012; Shimshack, Ward, and Beatty 2007; Teisl et al. 2011).

Organochlorine contaminants in farmed Atlantic salmon. An article published in the 9 January 2004, issue of Science reported that farmed Atlantic salmon (particularly from Scotland and the Faroe Islands) contained higher levels of organochlorine contaminants than wild Pacific salmon. The authors suggested that consumption of this particular fish should be limited to less than one and a half portions per month and concluded that consumption of farmed Atlantic salmon may pose risks that limit the beneficial effects of fish consumption. In response to this article, the UK Food Standards Agency immediately issued a press release, pointing out that the levels of dioxins and PCB's found in this study were in line with those previously found by the UK Food Standards Agency (FSA), and are within safety levels set by the World Health Organization (UK Food Standards Agency 2004a). On 9 January, the FSA issued a more detailed response highlighting that there is no reason to avoid eating Scottish farmed salmon or any other salmon (UK Food Standards Agency 2004b). Later, in 2004, an inter-committee subgroup consisting of experts from the British Scientific Advisory Committee on Nutrition and Committee on Toxicity issued a report suggesting that the UK population should be encouraged to increase its oily fish consumption to one portion a week to confer significant public health benefits without appreciable risk from the contaminants in fish (Scientific Advisory Committee on Nutrition 2004). The Science article and subsequent responses from the Scottish Salmon Industry, and FSA received substantial media attention in the UK (BBC News 2004; Highfield 2004).

In a cross-national European study conducted with 206 participants from Germany, Greece, Norway, and UK (van Kleef et al. 2009), participants were interviewed about recent food safety incidents in their home countries. Fifty-two participants from the UK were interviewed about their opinions regarding contaminated farmed Atlantic salmon incident. The results suggest that UK participants were generally confused about the conflicting information provided by the media reporting the Science article and FSA's response. They required more information about how guidelines on contaminants are developed and reviewed and wanted to be updated about follow-up activities such as investigations. They also reported that they do not trust the salmon industry because in their view the industry is more concerned about economic motivations than the safety of fish. Lack of trust in the farmed salmon industry was also found in more recent studies (Schlag and Ystgaard 2013), but was reported as not predicting consumption choices for salmon (Hall and Amberg 2013). In studies on other food safety incidents (e.g. BSE), consumption behaviors have been found to be affected by lack of trust (Pieniak et al. 2008; Rosati and Saba 2004).

Chronic contamination of salmon resulted in reduced levels of trust in food industry (van Kleef et al. 2009; Schlag and Ystgaard 2013). However, in order to quantify the effects of this increased risk perception and reduced trust on fish consumption, additional research is needed on people's attitude toward nuclear power. As part of this, it is important to segregate risk perceptions associated with farmed salmon from those associated with fish in general, in order to establish the extent to which risk perceptions have generalized to other fish or seafood species. Thus, without further analysis, the long-term public health impacts of this chronic food safety incident are unknown.

3.3. Radioactive contamination of food following a nuclear accident

Nuclear power has long been perceived as unacceptably risky by some members of the public. Incidents such as the Chernobyl accident have highlighted the potentially negative effects of a nuclear accident to human and environmental health in general (Drottz-Sjöberg and Sjoberg 1990; Renn 1990), and the human food chain in particular (BBC News 2011; Beach 1990). In the early 2000's, nuclear power has been repositioned as a solution to mitigate climate change because it has the potential to contribute to the growing demand for energy without emitting carbon dioxide to the atmosphere (International Atomic Energy Agency 2013; Sailor et al. 2000; US Department of Energy 2005; Whitfield et al. 2009), although its adoption in this regard is controversial (Sovacool and Cooper 2008). Accordingly, research has suggested people's attitude toward nuclear power is becoming less negative (Brook 2012; Goodfellow, Williams, and Azapagic 2011). However, the catastrophic Fukushima nuclear accident that occurred, following a tsunami, in Japan in March 2011 may have had a negative impact upon this trend toward more positive attitudes (Kanda, Tsuji, and Yonehara 2012; Poortinga, Aoyagi, and Pidgeon 2013).

Although not strictly a 'technological food production' related hazard, this case represents the occurrence of an acute food hazard with technological origins, where perceptions (based on those learned from previous examples of similar incidents) are formed rapidly under conditions of uncertainty, and are linked to unintended and uncontrollable effects of technology. In addition, perceptions are shaped by uncertainties associated with the geographic and temporal 'spread' of impacts, in particular immediately after the crisis has occurred (Hamada and Ogino 2012).

Research shows that most consumers (both in the country of the incident and neighboring countries) avoid purchasing products from affected areas in the aftermath of the incident and this avoidance behavior still continues in the following years although at a lower extent (e.g. Belyakov 2015; Hee et al. 2014; Sawada, Aizaki, and Sato 2014; Turcanu et al. 2007). However, avoidance from the food grown in contaminated areas also depends on food availability. For example, in the aftermath of the Chernobyl accident, many people continued consuming contaminated food due to poverty and lack of alternative food supply (Belyakov 2015). *The accident at the Fukushima Dai-ichi nuclear power plant (NPP).* On 11 March 2011, an earthquake of 9.0 magnitude created a powerful tsunami that flooded the Fukushima *Dai-ichi* NPP in Japan. As the flooding cut off power for cooling and created malfunction of all backup systems, reactors overheated, and a marked amount of radiation was released to the environment, including the Pacific Ocean.

The Japanese authorities evacuated citizens living within 20 km radius and suggested that people living in the radius of 20–30 km of the plant remain indoors. On 17 March , provisional standards for radioactivity in foods were established as radioactive contamination of food was observed in areas far from the NPP. These standards were subsequently revised and lowered in April 2011 (Baba 2013).

There were no initial deaths or serious exposures to radiation at the NPP. However, the evacuation resulted in 60 immediate deaths of patients or elderly people in nursing homes and health care facilities due to deterioration of serious medical conditions (González et al. 2013). On 16 December , more than 9 months after the accident, the Japanese authorities declared the plant to be stable, although acknowledging that it would take decades to decontaminate the surrounding areas (Buerk 2011).

The Japanese Government announced a comprehensive review of its energy policy to emphasize renewable sources. In addition, all NPP's in Japan have either been closed or had their operations suspended for safety inspections and maintenance. The accident has also affected other countries' future energy plans. In response to German citizens' rising concerns about nuclear energy as a result of the Fukushima accident, Germany announced plans to shut down all its nuclear reactors by 2022. Similarly, Switzerland agreed to phase out its five aging power reactors, and Italy decided to exclude nuclear energy from its future energy mix.

Communication efforts by the Japanese authorities to the public during and aftermath of the disaster have been widely criticized due to lack of transparency, downplaying the extent of the disaster, and failure to warn about likely events as raising concerns, as well as shedding doubt on credibility of the government (Figueroa 2013; Funabashi and Kitazawa 2012; González et al. 2013; Ng and Lean 2012; Poortinga, Aoyagi, and Pidgeon 2013). There is evidence from within Japan that public support for nuclear power, which was not high before the incident, has been further reduced (Figueroa 2013; Kato et al. 2013; Poortinga, Aoyagi, and Pidgeon 2013).

People's risk perceptions associated with nuclear contamination are extremely high, both in terms of general environmental contamination (Slovic 2012), and in relation to the food supply (Burger 2012). Thus, even a low level of radioactive contamination of foods may result in consumer rejection, even if the level of contamination is similar in magnitude to naturally occurring background levels of radiation. As a consequence, in the short term, foods which are technically safe to consume may be rejected by consumers (International Atomic Energy Agency 2013). This is particular concern in a crisis situation, for example, following a nuclear accident, where it may be difficult to provide adequate food supplies to the effected population as other crisis management activities (e.g. evacuation, provision of medical aid) may have higher priorities in terms of resource allocation. Given that contamination is likely to be perceived as ubiquitous within the region, short-term problems associated with under nutrition may occur (Spirichev et al. 2006). Thus, risk perceptions may result in acute nutritional deficiencies in a population which is dealing with multiple potential health, injury, and infrastructure concerns associated with the aftermath of an earthquake. In the long term, there is the potential for all foods produced or stored within the vicinity of the nuclear accident to be 'stigmatized' or rejected. Thus, consumer rejection of food produced in the affected region may have negative impacts on the local economy. This may extend beyond local consumers and affect export markets. National food production, unaffected by the nuclear incident itself, may be stigmatized, which will further impact on the national or even regional economy. In summary, such incidents may cause consumers to act rapidly to protect themselves from harm, but in the long term, their risk perceptions may 'stigmatize' foods produced within local production systems, with concomitant negative socioeconomic impacts. In a crisis, when food availability is potentially an issue, health problems associated with malnutrition may result from the perception that all local food supplies have been contaminated by radiation (WHO 2013). In order to quantify these relationships, it is important to measure risk perceptions and dietary choices immediately after the incident has occurred, as economic measures are unlikely to be reliable owing to multiple perturbances. Longitudinal analysis might usefully correlate economic data associated with local food production (both in terms of price and volume) with risk perceptions of local consumers, and consumers in export markets for local and national products.

3.4. GM animals applied to food production

GM technology has been applied to various crops, including those intended for food and animal feed, and to production animals (Cowan, forthcoming; Frewer et al. 2013a). However, food products derived from GM animals have not yet entered the US and European market, although regulatory approval appears imminent for some applications (Maxmen 2012; US Food and Drug Administration 2015a; Vàzquez-Salat et al. 2012). Medical applications based on pharmaceuticals derived from GM animals are more widespread internationally (Houdebine 2009, 2011), in particular in relation to disease models (Laible 2009; Prather, Shen, and Dai 2008). The use of GM animals in food production systems potentially confers benefits in terms of food safety, enhanced nutrition, and improved food security (Niemann and Kues 2007). Consumer perceptions of risk are higher for GM animal-related food applications than plant-related applications, and may militate against their use in food production. Other areas of application such as medical applications appear more acceptable to the public, primarily because the benefits are perceived to outweigh the risks (Frewer et al. 2014; Frewer et al. 2013b). Particular concerns are associated with animal welfare issues, and perceptions that negative environmental impacts may be associated with intended or unintended environmental releases of GM animals (Einsiedel 2005). What distinguishes the case of GM animals applied to agriculture to the other cases presented here is that it is associated not only with high levels of risk perception, but also high levels of moral or ethical concerns on the part of the public, particularly in the US and Asia (Frewer et al. 2013b).

GM *salmon destined for the human food chain.* At the time of writing, a GM salmon destined for human consumption has been approved for sale by Health Canada (Health Canada AquAdvantage Salmon 2016), and also approved as safe and nutritious to eat by the FDA (US Food and Drug Administration 2015b). The genetic modification increases growth rate (Aerni 2004), anticipating increased demand for fish and fish products over the coming decade (OECD and Food and Agriculture Organization of the United Nations, forthcoming). Accordingly, GM fish has been considered as a sustainable solution in terms of food security. Atlantic salmon is one of the food species that has been subjected to GM (Menozzi, Mora, and Merigo 2012). It has been argued that GM salmon offers nutritional advantages, including resistance to environmental stressors and pathogens, and increased availability of omega three fatty acids (US Food and Drug Administration 2013a). Disadvantages may be associated with the need to ensure allergens are not introduced into the human food chain (Nakamura et al. 2009), and less than 100% sterility resulting in potential cross-breeding with wild varieties of salmon (Le Curieux-Belfond et al. 2009). The advantage for consumers may be economic (retail price reduction), or nutritional (increased availability of foods rich in heath promoting components) (Mora et al. 2012). Against this, the issue of environmental impact (for example, unintended release of animals into the environment and animal welfare concerns) remains a potential source of controversy (Frewer et al. 2014). One recent study (Mather, Vikan, and Knight 2016) that measured Norwegian consumers' willingness to purchase GM-labeled salmon found aversion to GM animal concept and highlighted the necessity of communicating consumer benefits for GM salmon to be accepted in markets where GM labeling is required. Therefore, the primary drivers of risk perceptions, at least in Europe, appear to be perceptions that the application of GM technologies to animals is risky. Consumers in North America and South-East Asia tend to be more concerned about moral and ethical issues (Frewer et al. 2013b). The lack of equity of distribution of benefits across different countries and across populations is regarded as another potential issue militating against the development of such production animals. Perceptions leading to consumer rejection are not linked to the use of GM animals per se, but rather focused on their use in the food supply chain.

In the case of GM animals used in food production, it is difficult to argue that consumers' risk perceptions militate against their own interests. It could be argued that lower prices for animal proteins high in beneficial nutrients represents a considerable consumer benefit which will deliver advantages to public health, although this may not be such an important benefit given that early innovations are destined for more affluent countries (Menozzi, Mora, and Merigo 2012). Of potentially greater importance regarding consumer adoption is the issue of how moral and ethical concerns contribute to rejection of GM animals in food (Kaiser et al. 2007). It is suggested that the principle of informed choice, through adoption and implementation of an effective traceability and labeling policy, will prove beneficial *if* and *when* products are released into the market. Even if consumers perceive that adequate risk assessment procedures are introduced, that animal welfare standards are met, and that governance structures are adequate, perceived benefits may not outweigh moral and ethical concerns. However, providing further information about risk and benefit assessments is unlikely to alleviative these, and this is what distinguishes the GM case for the others presented in this paper. In this case, measuring moral concerns, and how these change (for example, after the initial commercialization of products developed using GM animals) may be a useful tool for developing policies further.

4. Discussion

Four food safety cases where risk perceptions associated with the food hazards have been presented. In three of these (*E.coli* outbreaks, linked to fresh spinach and fenugreek sprouts, organochlorine contaminants in farmed salmon, and radioactive contamination following the Fukushima accident), it was concluded that risk perceptions may lead consumers to behave in a way contrary to their own, and societal interests. In the fourth (GM salmon destined for the human food chain), moral concerns may influence consumer behavior to a greater extent than risk perceptions. In relation to these cases, how technological vs. natural and acute vs. chronic nature of food hazards affected people's risk and benefit perceptions, and associated attitudes and behaviors, has been examined.

An initial starting point to examine the acute vs. chronic dimension is that in risk assessment more is known about the acute effects of a food safety incident compared to long-term impacts, in particular when examining (changes in) risk perceptions and subsequent consumption behaviors. In the case of the *E. coli* outbreaks, and the reporting of contamination of Atlantic salmon, short-term impacts can be 'metricized' through analysis of changes in risk perceptions and consumption and sales patterns. The long-term impacts on dietary choices have not, to our knowledge, been analyzed, and it is not clear how risk and benefit perceptions affect dietary choices in the long term. These chronic effects are particularly complex because vulnerabilities to the risk change through the lifecycle of consumers (for example, with respect to age and immune status) (Ma and Fang 2013; Wada et al. 2013), and also vary between different demographic groups (for example, with respect to gender) (McCombe, Greer, and Mackay 2009; Yan et al. 2010). In addition, improved scientific knowledge, for example about toxicology may result in food choice dilemmas in the future. A recent example is that of inorganic arsenic in the food supply (Llorente-Mirandes et al. 2014), where reports of relatively high levels of arsenic in vegetables may fuel consumer risk perceptions, with the consequence of reduced vegetable consumption. This reduction may lead to net negative impact on long-term public health. Longitudinal assessment of the relationship between risk perceptions and consumer choices is required. Linking these data with economic assessment would be useful in order to determine the socio-economic impacts (for example, to local producers in the case of Fukushima). In the case of GM Salmon, such analysis would need to be projected at present, as approval is pending. If approval is given to commercialize GM salmon in the human food chain, there may be ample opportunity to assess the relative influence of consumer risk perceptions and moral and ethical concerns, on purchasing and consumption. Analysis of external changes (for example, societal debate about synthetic biology applications in food production) might further crystallize public opinion regarding the biological sciences in general (Torgersen 2009; Torgersen and Schmidt 2013).

The analysis of the cases over the risk origin (technological vs. natural) presented support for the contention that technologies applied to food production are associated with higher levels of risk perception, potentially because they are perceived to be unnatural. However, the available evidence suggests that intrinsic (or intuitive) consumer concerns about ethical or moral issues are closely associated with the introduction of GM animals applied to food production, more than ‘objective’ hazards like health risks. The issue of whether alternative, less controversial, technological approaches may be available to deliver the same benefits may also need to be considered, as this is an issue influencing consumer acceptance (Gupta, Fischer, and Frewer 2012). In contrast, while it is possible to construct extrinsic ethical arguments regarding the risks of nuclear power (for example, the potential for environmental harm), this would relate to risks of a nuclear accident, rather than a concern located in the development and application of the (enabling) technology itself.

The importance of developing trust has been highlighted in all of the cases, although this may have greatest impact in terms of long-term consumer responses to risk–benefit communications (Berg 2004; Frewer et al. 2015). Communicating risk uncertainty to the public has emerged as an important issue. Therefore, communicating transparent and honest information, in particular telling the consumers what the authorities know and do not know, with clear recommendations for actionable behavior changes if relevant, may increase trust in information following the occurrence of a food safety incident (Frewer et al. 2015; Kaptan and Fischhoff 2010). Communication of uncertainties associated with the scientific assessment of risks and benefits may also be relevant where these exist, and need to be communicated to consumers in terms of consumer protection or the generation of consumer confidence in information (Beck and Kropp 2011; Thompson 2002). In the case of both acute and chronic risks, it is noticeable that transparency about new scientific information, novel technologies, and internal decision-making processes of regulatory agencies rises as an important determinant affecting risk perceptions.

The Fukushima accident case exemplifies the importance of prior attitudes and value orientations toward nuclear power in risk information, suggesting that there is no single public with regard to energy preferences and corresponding risk beliefs but rather there are multiple populations with different viewpoints (Greenberg and Truelove 2011; Whitfield et al. 2009). This result seems to some extent similar to those of experimental studies involving prior attitudes toward food (Fischer and Frewer 2009; Van Dijk et al. 2012).

In all the cases presented here, consumers needed to make informed decisions by understanding and balancing their decisions regarding both risks and benefits associated with associated food choice behaviors. If relevant risk–benefit information is not available, people may rely on judgmental heuristics, or rules of thumb such as availability heuristic (Gilovich, Griffin, and Kahneman 2003; Kahneman, Slovic, and Tversky 1982). The availability heuristic may explain why foods are rejected when only risk information is provided. As a consequence, the associated risk attitude will be the most available and most influential attitudinal influence on consumers' decisions. Other inferences are derived from people's existing mental models allowing them a framework to interpret issues in the news media, participate in discussions, feel competent to make decisions, and generate options (Fischhoff 2009). Mental models can provide essential structure in understanding risk communication, but also produce incorrect conclusions if they contain incorrect beliefs and/or misconceptions. Therefore communications need to be tested before (and evaluated after) they are utilized because mental models of risk communicators and the target audience may be different, thus leading to unexpected impacts of the communication.

It should be possible to extrapolate the results of the case studies presented here to emerging food risks, where there is little existing data regarding risk perceptions. Emerging food risk issues include synthetic biology (both in general and as applied to food production) (Pauwels 2013), increased mycotoxin levels in the global food supply (Wu 2006), and inorganic arsenic in food and water (Moreno-Jimenez, Esteban, and Penalosa 2012; Smith and Steinmaus 2009). The case studies highlight an important research need in the context of examining the relationship between risk perceptions and impacts (whether on health or socioeconomic functioning of affected societies). While there is some evidence to assess the short-term impacts of food risk events (for example, in relation to sales volumes of foods and food commodities associated with a food risk incident), the long-term impacts are not understood, as other external factors also influence consumer demand. Developing metrics to assess this would not only enable greater understanding of the relationship between risk perceptions and consumer behaviors, but also allow mapping of the 'stigmatization' following a risk incident of foods in potentially affected food chains or regions. The analysis of big data, in particular internet searches and social media activity such as Twitter may serve to link perceptions and concerns to food safety incidents (Wilson and Brownstein 2009). While such analyses may be limited in terms of pinpointing local incidents, in particular in developing countries (Carneiro and Mylonakis 2009), consumer concern following an announcement of such incidents can be monitored, and risk communication adjusted accordingly. In addition, methods to simultaneously quantify risk perceptions, psychological impacts, and impacts on local and regional economies are needed, which have to be utilized in conjunction with assessments of public health and environmental impacts, possibly utilized the same models. Methodologies which can harmonize natural and social science data sets are needed to generate predictive power in this respect.

5. Conclusions

In this study, two axes, risk origin (natural vs. technological) and acute vs. chronic dimension have framed the analysis of four different food safety incidents. In the case of the 'naturally' occurring incidents, it was concluded that there is potential for risk perceptions to override consumer best interests from the perspective of optimal nutrition (in particular relative to under consumption of health promoting nutrients). In the case of technological potential hazards (e.g. a food safety incident linked to a nuclear accident), consumers own interests may also be harmed in the short term, and therefore developing a comprehensive understanding of consumer perceptions as well as technical risk estimates is needed to develop effective communication. In the case of GM animals applied to food production, other concerns, which are potentially moral or ethical in nature, may be more relevant to consumer acceptance than their risk perceptions. In this case, it is difficult to argue that consumer risk perceptions are operating contrary to their own interests. The principle of consumer choice (implemented through effective traceability and labeling policies for GM animal food products) may allow consumers to make judgments according to their own ethical priorities, although this will not be helpful for those individuals for whom a moratorium on, or discontinuation of, research is required. In the case of acute and chronic food safety incidents, long-term analysis linking perceptions to robust measures of impact is important but infrequent. Future research should aim to quantify the links between risk perceptions, behaviors economic effects, and public health and environmental risk indicators.

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