# AGENT-BASED MODELLING OF SOCIAL RISK AMPLIFICATION DURING PRODUCT CRISES

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# DECLARATION

This thesis is my own work, and it has not been submitted for the award of a higher degree elsewhere.

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# ABSTRACT

Public response to risk is socially shaped in a way that often over- or under-estimates expert risk assessments. One of the main theoretical tools to examine public risk perception is the social amplification of risk framework (SARF). This framework proposes a mechanism through which risk responses arise from interactions among various social actors, but past empirical work has been mainly concerned with correlations between structural variables rather than the mechanism of amplification and the process over time by which it develops. And more importantly, there has been quite limited modelling of risk amplification to date. This study aims to discover a way of formalising social risk amplification, to find out what are the necessary assumptions for modelling risk amplification, and to work out what consequences this modelling would predict. It is an attempt to model collective response to risks that are significant at a societal level but which materialise in a distributed way across a population. The natural heterogeneity of individual risk perceivers, the emergence of behaviour through interactions of social actors, and the complex feedback loops linking risk perception with risk related behaviour point to using an agent-based model as a modelling medium.

The study is developed in the context of product contamination scandals such as the recent cases in China of contaminated milk products. One of the important features of contamination crises is that product recall has become an increasingly inevitable part and is often a key element in risk communication during such crises. Yet recalls send ambiguous signals about the misconduct of the organization in question: they clearly indicate some kind of failure, and possibly negligence, in the product that are associated with a risk of significant harm; but they also suggest that the organization is concerned with consumers' welfare.

The model that was developed is based on the principle that risk perceivers have to assimilate risk through the risk beliefs of others, their direct experience of a risk, and communications about the risk from organizations (including their product recall decisions) and the media. And it is based on the principle that, as well as discovering the nature of a risk, risk perceivers also make judgments about wrongfulness (which Freudenburg called recreancy) – and this also shapes the strength of risk responses.

The model is partially calibrated with a consumer survey carried out in the context of a Chinese milk contamination scandal that took place in recent years. Simulation results from the model show that public risk perception grows progressively toward an exogenous peak before it immediately decays, and that there is a relatively high residue of concern after the crisis is resolved. The objectivity of media coverage appears to be inversely related to risk amplification: a media that simply follows public opinion is associated more strongly with exaggerated risk perceptions than an objective one. A sensitivity analysis indicates that the

initial conditions, objective risk level, duration of contamination, and variation of recreancy perception are the most significant influences on the degree of social amplification. This knowledge helps prioritize data collection for future research and identify important aspects that particularly require managerial attention.

The main contribution of this study is to develop a process of modelling social risk amplification that consists of three steps of increasing contextualisation. The first step involves a basic model that captures social risk amplification as a general theory relative to all kinds of risk event. The second step contextualises this model specifically for product recall crises. It involves extracting agent decision rules from the literature on product recall, based on statistical associations found in empirical work on recall crises. And the third step contextualises the model for a specific population. It involves calibrating the relative importance of different information sources for the heterogeneous agent population using a survey of Chinese consumers responding to a milk contamination crisis. One important insight from the process of modelling risk amplification is that SARF is not sufficient for modelling particular crises. It seems essential that modelling of SARF should involve a clearly defined context in which risk responses arise.

# CONTENTS

# 1 INTRODUCTION

This chapter gives an introduction to this study in five aspects – the research problem that it tackles, the theoretical approach that it is based on, the context in which it is conducted, the objective that it attempts to achieve, and the layout of the thesis.

## 1.1 Research problem

Risk perception appears to hold a central position in the social and organizational agenda and is crucial for the understanding of social processing of uncertainty (Rogers, 1997). Management and communication of risks have become a dominant concern of many organizations, government agencies, and scientific research groups in modern society. It has long been accepted that public perceptions of risk are socially shaped (Muter et al., 2013; Scherer and Cho, 2003). Specifically, how people perceive and respond to risks is a reflection of social context they find themselves in (Sjöberg, 2000). An individual's reaction to risk is often accompanied by communicating with others, processing related risk information, and modifying risk behaviour accordingly. Thus the judgments that people make about risks or risk events are more a question of social interaction and observation than of merely anticipated physical consequences (McComas, 2003; Mitchell, 1995).

Importantly, collective response to risks is not always accurate with respect to the objective level or expertly-estimated level of risk but deviates considerably from it (Kasperson and Kasperson, 1996; Liu et al., 1998; Loewenstein and Mather, 1990). There is often a dramatic divergence between expert assessment of risk and public perceptions of risk, as seen in such cases as SARS in Hong Kong (Lau et al., 2003) and genetically modified foods in the UK (Frewer et al., 2002). The divergence produces social reactions that result in negative public attitudes toward risks or technologies, societal costs, and economic losses, which create, as Busby and Onggo (2013) have pointed out, 'an obstacle both to managing risks specifically and to introducing new technology more generally'. For example, according to Siu and Wong (2004), the SARS outbreak severely affected tourism, travel, and retail sales in Hong Kong, with visitor arrivals dropping by 63% (around 850,000) and retail sales falling by 14% (around HK$2 billion). It becomes essential, therefore, to understand the question of how people collectively perceive potential danger and form risk responses.

## 1.2 Theoretical foundation

One of the main approaches for explaining public risk perception is the social amplification of risk framework (SARF) (Kasperson et al., 1988). SARF aims to explain how risks or risk events that are considered minor by technical experts produce strong public concern and substantial social and economic consequences. A risk event is portrayed through risk signals that interact with psychological, social, institutional, and cultural processes in ways that can heighten or downplay public perceptions of risk and related risk behaviour. The notion is that risk signals are created, transferred, and interpreted by a variety of social actors that are seen as 'amplification stations', such as individuals, news media, social groups, government agencies, scientific institutions, and so on. The term 'amplification stations' were proposed in the original article of SARF (Kasperson et al., 1988) to represent social actors that experience a risk event and generate, transmit, and process information about the risk. Amplification here refers to a difference between subjective and objective assessments of risk and includes both overestimation and underestimation of risks. Risks will become amplified if the subjective risk beliefs of the public are higher than the objective risk but attenuated otherwise.

The social processing of risk signals is accompanied by behavioural responses that are likely to evoke secondary impacts, such as loss of trust in institutions, loss of sales, demand for regulatory constraints, litigation, changes in physical risk, community alienation, and stigmatization of product, that spread far beyond the initial impact of risk events (Kasperson, 2012; Kasperson et al., 1988; Renn et al., 1992).

In accordance with SARF, social experience of risk is not merely an experience of health and safety impacts, but rather the result of the process by which individuals and social groups learn to analyse the nature and effects of risky events by gathering and processing relevant risk information from the physical world and the social world (Burns et al., 1993; Kasperson and Kasperson, 1996). The concept of social risk amplification provides a theoretical base for explaining individuals' perceptions of risk as well as an analytic framework for exploring the social processes by which risk responses are made.

There has been a large amount of empirical work around the idea of risk amplification. However, as detailed in the Literature Survey (Chapter 2), almost all past empirical work on social risk amplification has been concerned with the correlations of structural variables in risk amplification rather than the mechanism that produces risk amplification. And more importantly, there has been quite limited modelling of risk amplification to date. Examples seen in the literature have used both system dynamics (Burns and Slovic, 2007; Busby and Onggo, 2013) and agent-based models (Busby et al., 2016; Onggo et al., 2014) to explore the mechanisms of risk amplification. Their primary concern has been how social communication influences the formation of risk beliefs. This concern has meant that other factors shaping risk

responses have received little attention. One is organizational misconduct, which is termed 'recreancy' and defined as the belief that the producer has betrayed the public trust and fails to fulfill its obligations (Freudenburg, 1993). Freudenburg (2003) has argued that recreancy is probably the most important contributor to social risk amplification. This combines with but does not replace direct experience in the formation of risk responses. Direct experience obviously serves as a source of information by providing feedback on the nature and controllability of hazardous events (Kasperson, 2012; Kasperson et al., 1988). But as Rogers (1997) pointed out, although direct experience can lead to learned perception and is an important basis of public risk estimates, it may be very limited in many contexts for many of the more contentious, societal-level risks.

## 1.3 Research context

Product contamination crises have been one of the most pressing problems faced by organizations (Siomkos and Kurzbard, 1994). They are seen as well-publicized occurrences wherein products are found to be contaminated with a biological, chemical, or physical agent and could cause adverse health effects. Factors such as the increasing complexity of products, customers being more demanding (Dawar and Pillutla, 2000; Laufer and Coombs, 2006), and increasingly advanced and, at the same time, vulnerable technology (Standop, 2006) have made contamination incidents even more frequent. Moreover, as indicated by such cases as the milk contamination incident in Oahu, Hawaii, in 1982 (Liu et al., 1998) and contaminated pet food in the United States (Feng et al., 2010), product contamination incidents often dominate media space and elicit extensive public concern, creating great challenges for the organizations' handling of associated risks.

To find an appropriate case that can be used as a reference for this study, three cases that occurred in China in recent years are outlined in the Research Context (Chapter 3) – the 2008 Chinese milk scandal, the Nongfu Spring water event, and the 'gutter oil' scandal. These cases all involved a well-defined contaminated product, an intense social reaction, and multiple types of actors (e.g. firms, government, and the public) engaged in risk communication processes. In one of the three cases – the Sanlu milk scandal – there was a single producer who made decisions about whether, when, and how to implement recalls of defective products. Product recalls have become a prevalent phenomenon (Copeland et al., 2004; Germann et al., 2014) and have been recognized as a top priority for dealing with contamination crises (Hora et al., 2011; Magno, 2012). They introduce a clear organizational activity that poses two contrary effects on consumer perceptions of risk: product recalls are a primary source of information regarding potential risks that consumers are facing, while they are also

demonstrating that the producer is seeking to solve the problems and to protect consumers from being harmed by products in question. As a consequence, the context for this study is a specific product contamination crisis in which the organization involved makes a product recall, with the Sanlu milk scandal as the prototype case.

## 1.4 Research objective

The objective of this research is to investigate the process of modelling risk amplification. This includes:

1) identifying the key elements of SARF that need to be incorporated in a model of risk amplification mechanisms;

2) identifying the main assumptions that need to be made in the construction of this model;

3) determining what kind of decisions are required when the model is applied to product contamination crises;

4) finding a suitable process of calibration;

5) assessing what insights can be gained from simulating the model and performing sensitivity analysis on the results.

The inherent heterogeneity of individual risk perceivers (Sjöberg, 2000), the emergence of behaviour through interactions of social actors (Binder et al., 2011; Smith et al., 2013), and the complex feedback loops linking risk perception with risk related behaviour (Burns and Slovic, 2007; Busby and Onggo, 2013; Busby et al., 2016) point to using an agent-based model as a modelling medium. As discussed earlier, such a model is developed in the context of product contamination scandals such as the recent cases in China of contaminated milk products.

In the model there are a relatively large number of public agents (typically 1,000), a single producer agent, and a media agent. The conceptualisation of an individual agent forming risk perceptions during a recall event is composed of three primary elements. The model separates individuals' responses into a risk discovery element that integrates prior beliefs, beliefs of social neighbours, direct experience, and producer announcements and a recreancy judgment element that is assessed by the timing and voluntariness of recalls. It is also an important step to combine narrowcast and broadcast information channels among a population of public actors interacting in a fixed social network. Public agents use very simple linear rules to update their risk beliefs. The model is partially calibrated by a consumer survey to achieve a certain level of micro-validity and to further contextualise social risk amplification.

The intended contributions of the work mainly lie in two aspects. One is to develop a process of modelling social risk amplification through three main stages of increasing

contextualisation – involving the extraction of agent decision rules from the literature and calibrating agent priorities from a survey. The second is to show with the model which are the aspects to which risk amplification is most sensitive. The main practical value of the study is to show policymakers and risk managers who need to deal with public risk responses how to reason about the problem of how such responses are formed. Perhaps most significantly, the model helps managers reason about the effects of early or late product recalls, and helps them deal with the dilemma that product recalls can be both harmful and beneficial to a producer's reputation. And thinking about the role of the media as leaders or followers of public responses has been shown to make an important difference.

## 1.5 Layout of thesis

The remainder of this thesis is structured as follows. The next chapter reviews the literature on social risk amplification to describe the main theoretical and empirical work that has emerged from SARF. Chapter 3 briefly depicts and compares three product related crises that arose in China in recent years, justifying the choice of one of them as the reference context in which the model is built. In Chapter 4 the design of this study is presented including the research questions to answer, reasons for using agent-based modelling as a medium, and the procedure for conducting empirical work to support calibration of the model. Then Chapter 5 deals with the development of the agent model and shows the results of simulating the model in a perfectly mixed population and in a small-world network, respectively. Chapter 6 calibrates the relative importance of different sources of risk information for public agents using a consumer survey of Chinese people responding to a milk contamination crisis. Chapter 7 evaluates the uncertainty in the model through sensitivity analysis and assesses the model's micro- and macro-validity. A general discussion is given in Chapter 8 to illuminate how the model proposed in this study helps us better understand SARF, the balance between generality and contextualisation represented in the model, and how the model addresses the research questions. The thesis concludes with a statement of the intended contributions and an indication of the study's limitations as well as of directions for future work.

# 2 LITERATURE SURVEY

This survey attempts to organize, describe, and evaluate the current literature on social risk amplification. The findings will be used in Chapter 5 for the development of decision rules behind social risk amplification in the conceptual agent model. This review is structured as follows. The first section deals with theoretical background of risk amplification. The second section outlines and critically comments on empirical work in terms of actors (media and non-media actors), contributory effects, contexts, and methodologies. The third section surveys the existing modelling of social risk amplification. This review ends with a brief discussion and conclusion.

## 2.1 Theoretical background of risk amplification

The social amplification of risk framework (SARF) (Kasperson et al., 1988) was originally proposed to portray why and how certain risks attract public concern and become either heightened (through an amplification process) or lessened (through an attenuation process). In other words, SARF is regarded as an integrative framework that can be used to conceptualise and understand the dynamic complexity of risk perception within a social system (Duckett and Busby, 2013; Renn et al., 1992). SARF draws upon the notions that there is a serious disjuncture between expert assessment of risk and public perceptions of risk, and that an adequate conceptual framework is essential to provide guidelines on how to model and measure the functional relationships among various factors related to specific risk events (Kasperson et al., 1988).

The metaphor of amplification explicitly comes from classical communication theory and signifies the process of amplifying or attenuating risk signals through dissemination of information between transmitters and receivers that act as amplification stations such as individuals, social groups, institutions, and media outlets (Binder et al., 2011; Kasperson, 2012; Kasperson et al., 1988). In practice, distortion of risk signals occurs during both transmission and reception. Risk information is filtered and interpreted by various individual and social amplification stations that tend to heighten or weaken the salience of certain information in accordance with their own attitudes, values and beliefs. The behavioural and communicative responses of social actors are often drivers of secondary impacts that in turn trigger another stage of amplification to produce tertiary impacts. These 'ripple effects' suggest that amplification can 'extend the temporal, sectoral, and geographical scales of impacts' (Kasperson, 2012).

According to SARF, the social amplification of risk is the 'the phenomenon by which information processes, institutional structures, social-group behaviour, and individual responses shape the social experience of risk, thereby contributing to risk consequences (Kasperson et al., 1988). Risk amplification occurs at multiple stages, including dissemination of risk information and related exaggeration, underestimation or otherwise distortion of risk perception, as well as subsequent societal response mechanisms. It should be noted that direct experience can sometimes serve as a risk amplifier or attenuator by providing feedback on the nature and controllability of hazardous events in reality. But to a large extent, awareness and knowledge of a risk is not acquired through direct experience. Specifically, mass media, interpersonal communication, and social interaction play pivotal roles in not only transmitting risk information but also framing and interpreting risk issues (Chung, 2011; Kasperson and Kasperson, 1996; Smith et al., 2013).

In particular, the media that are usually represented by television, newspaper, radio, and increasingly, the Internet, occupy a vitally important and often conflicting role in shaping public perceptions, attitudes, and reactions to risk. Extensive media coverage on controversial natural, social, or technological risks can evoke strong social attention or public concern (Frewer et al., 2002; Koné and Mullet, 1994). It is generally held that media coverage is the mirror of risk perception, since the media are likely to allocate coverage disproportionately to rare or dramatic risks or risk events (Combs and Slovic, 1979; Kasperson et al., 1988). But this is not necessarily the whole story especially when potential contributors to risk perception are taken into account in the particular context to which the risk is specifically sensitive.

Interpersonal communication, which involves the linkage with friends, neighbours, colleagues, and relatives, can also act as an agent of risk amplification in the way that people tend to neglect risk issues in isolation from views of their peers and share preference points or seemingly biased opinions with each other (Kasperson, 2012; Kasperson et al., 1988; Stanciugelu, 2013).

With respect to social interaction, risk perceptions and risk-related responses are situated within a broader context where most risks are conceptualised, measured, and manipulated by social groups and institutions. The behaviour and interactions of institutions and organizations largely reflect their rules, functions, interests, and expectations that affect their predispositions in terms of risk interpretation and risk control (Renn et al., 1992).

In addition to individual and social stations, the symbolic connotations of risk information such as language, images, videos, and signs are also responsible for risk amplification, because specific concepts or terms used in risk communication may mean quite different things to various individuals and social groups (Kasperson et al., 1988; Petts et al., 2000). In other words, the same story with the same information can be told in different ways, so such

symbolic connotations may entail the tendency to intensify or downplay related risks or risk events.

There have been some criticisms of SARF, although it has become a standard lens that is widely used by researchers, risk managers, and policymakers. Rayner (1988) argued that the metaphor of amplification assumes risk signals to exist externally and objectively. Rayner (1988) held that risks do not exist outside the social system but relate closely to social actors that contribute and are subject to social processes. Correspondingly, risks are not 'things' independent of perceivers, but complex relationships of human and nonhuman components. Rip (1988) similarly stated that 'a hazard signal is not just information-to-be-processed, but includes a (subculturally determined) action precept, or just a general call for action without prescribing any yet'. Rip's criticism is also that analysis and evaluation of effects of social responses are markedly absent in SARF, and that the discussion concentrates on the individual in light of information communication and response mechanism and neglects the processes of social aggregation.

The starting point of SARF is that there is a divergence between expert assessment and lay risk judgments. But Duckett and Busby (2013) argued that the authors of SARF do not explicitly point out whether expert assessment denotes a baseline risk from which social amplification is regarded as an unfavourable distortion. SARF fails to address the idea that 'commonsense judgments about other people's risk behaviour often involve attributions of disproportionality' (Duckett and Busby, 2013). Thus risk issues that seem overblown for one group are generally not being exaggerated by other groups. As Duckett and Busby (2013) suggested, additional layers of complexity exist among experts and the lay public. Besides, competing discourses are involved in the debates about the proportionality of risk response. Thus it is difficult and challenging to make objective comparison between expert risk assessments and lay judgments. Yet, in spite of the above critique, SARF has proved and continues to be successful and influential as an integrative and heuristic framework in the risk management arena.

## 2.2 Empirical evidence of risk amplification

In this section the issue of empirical evidence is divided into four parts – the actors involved in risk amplification processes, the contributory effects shaping risk perception, the contexts of risk events dealt with in empirical work, and the methodologies by which risk amplification has been examined.

## 2.2.1 The actors in risk amplification

There are two types of actor clearly differentiated in the literature: media and non-media (e.g. the public, government, NGO, organizations, etc.). This section reviews how the two types of actors contribute to social risk amplification, respectively.

### *Media in risk amplification*

It has been argued that a number of attributes of information about a risk event are responsible for social risk amplification (Kasperson et al., 1988). The news media, serving as an important channel of information flow, have received extensive scientific attention for their critical role in communicating risk and shaping public risk perception.

Current empirical work has paid close attention to the effect of media coverage on public perceptions of risk. It is noted that negative media coverage and positive media coverage produce asymmetrical effects on perceived risk for milk contamination in Oahu, Hawaii (Liu et al., 1998). Negative media coverage has immediate effects on individual behavioural responses due to consumers' dislike of adverse health effects, while positive news reports do not have a quick impact because it takes some time for consumers to slowly adjust their perceptions to their perceived risks before the contamination is revealed.

Kasperson and Kasperson (1996) pointed out that the news media generally cover risks selectively. For example, the media tends to downplay commonplace but more serious risks yet emphasize those that are rare or dramatic. However, in some countries, the media actively pursues aggressive risk intensification or risk attenuation for the interest of social institutions or governmental agencies. In China, for example, the news media have to accept the Communist Party's guiding ideology and comply with the Party's press policies, and the media have to design their coverage to support the Party's guidance in political and social life (Zhao, 1998).

Frewer et al. (2002) examined how media reporting about the risks associated with genetically modified foods affects public attitudes toward the technology, and concluded that there was consistency between the pattern of reporting and the changes in risk perception. In other words, individuals who perceived media reports as more alarming showed greater increases in risk perceptions compared to those who were less alarmed by the reports.

In terms of media use, a sociological survey on earthquake risk perception of residents in Bucharest city reveals that television remains the main source of information in case of disasters or accidents (Stanciugelu, 2013). According to an empirical study on citizen engagement with wildlife risk (Hart et al., 2011), in comparison to newspapers, television news plays a larger role in influencing the risk perception of the threat that wildlife poses to

humans, since television is more likely to intensify perceived risk of wildlife by presenting vivid images, dramatic plots, and negative emotional content. By contrast, Yeo et al. (2014) noted that television news, newspaper stories, and online media coverage could mediate risk perception toward nuclear power within the American public before and after the Fukushima Daiichi disaster in Japan. Individuals who paid comparably higher level of attention to news saw larger decrease in risk perceptions after the disaster and vice versa.

Media use also played a vital role in determining the risk evaluations of ideological groups. For example, the less attention conservatives paid to media the smaller drops in risk perception they experienced (Yeo et al., 2014). Moreover, Chung (2011) has investigated the dynamic process of risk amplification in the Internet environment through an examination of public concern for environmental risk associated with a tunnel construction. It is suggested that the intensity of public concern does not necessarily correspond with the amount of press coverage or the number of news articles. What can be concluded from this position is that the public is quite active in appreciating risk-related information, in responding to media reporting, and in becoming involved in the adjustment process of their perceptions (Chung, 2011). In the same way, an empirical study that puts emphasis on wildfire risk perceptions among homeowners residing in a wildland-urban interface demonstrates that information provided by the media is not significantly correlated with risk perception (Smith et al., 2013). This result could probably be explained by the location of the study, where wildfire programs are actively implemented.

As discussed above, the media can either make risks seem disproportionately large or oversimplify the complexity of the issues. But this is not always the case. A study on the Canadian case of BSE in Alberta suggests that media coverage led to neither an exaggeration nor moderation of risk associated with BSE by providing accurate depictions of possible economic and health risks brought by BSE and vCJD (Boyd and Jardine, 2011). In a nut shell, the mass media plays multiple and sometimes conflicting roles in the risk debate (Kasperson and Kasperson, 1996). It not only conveys risk information to the public, but serves as an amplifier, an attenuator, or an impersonal narrator of risk events. Thus, as existing literature indicates, the media may impose positive, negative, or even no impact on perceived risk within the public. This variation may partly lie in the fact that different risk events occur in different places with distinctive cultural and social contexts. Under certain circumstances, local context plays a prominent role in the amplification or attenuation of the risk (Boyd and Jardine, 2011; Lewis and Tyshenko, 2009; Masuda and Garvin, 2006; Smith et al., 2013). It is reasonable to infer that the same risk event that occurs in different regions can produce different assertions pertaining to the relationship between risk perception and media coverage.

In practice, there is basically no literature evaluating the influence of social risk amplification on mass media. Nevertheless, it is undeniable that social amplification

associated with environmental, technological, and social risks can spawn considerable effects at the level of risk management, such as new regulations and policy decisions, and proactive risk communication strategies. These effects may restrict or enable what the media does (follow the pace of risk experts or regulatory agencies, or actively anchor public opinion), where the media obtains risk information (for example from whistleblowers or experts), what the media presents (accurate information or distorted portrayal), and what language of risk the media uses (the extent of dramatization and the symbolic connotations of information). Moreover, if the media notices that the risk of a hazardous event is socially amplified, in most cases it would frequently publish news stories referring to the event in order to cater to the interest of regulators and the public. This situation will probably increase individuals' ability to recall the risk and heighten their perception of the likelihood of the hazard occurring, resulting in a reinforcing feedback loop of risk amplification. How risk amplification affects media is quite important for modelling the role of media in shaping public understanding of risks or risk events and merits further investigation.

## *Non-media actors in risk amplification*

The media, in isolation, is unlikely to account for risk amplification (Chung, 2011; Frewer et al., 2002). The argument that risk perception is a mirror of media coverage cannot be always justified (Renn et al., 1992), because there are other non-media agents within the social amplification of risk framework that can affect public concern. For instance, the public, government agencies, commercial organizations, and NGO (non-governmental organisation) might operate as amplification stations to exert a strong influence on risk perception.

Interpersonal communication has received relatively little attention in the research on risk amplification. Binder et al. (2011) investigated the influence of interpersonal discussion on individual perceptions of risks on the basis of a public opinion survey of residents living in potential locations for a new biological research facility in the United States. The results showed that discussion frequency functioned as both an amplifier and an attenuator of risk judgments in relation to the facility, with a small positive influence on supporters and a significant negative influence on opponents. Researchers also investigated the potential influence of public meetings on risk perception by examining individuals' predisposition toward a local environmental hazard. The findings suggested that attendees perceived greater risks than did nonattendees, and that risk perception increased with the number of meetings attended (McComas, 2003). Moreover, individuals' online posts and comments to certain risk could generate amplifying ripples of public concern (Chung, 2011).

The interaction between the public and the expert groups is also a contributory factor to risk amplification. In the case of fishing and fish consumption, the public exhibited

attenuation of risks from fishing even if they were in the face of consumption warnings – the risks the public perceived were much lower than the risk estimates of the scientists and regulators (Burger, 2000). Mixed and conflicting messages concerning fish consumption and fishing, and economic benefits from fishing for both the public and governmental agencies enabled the public to discount the warnings, thereby fostering the deamplification (i.e. attenuation) of risk.

Arguably, the interactive dynamics between the public and elements in the social networks play a role in influencing the general public's perception of risk. The Canadian public showed attenuated perception of risk after BSE (bovine spongiform encephalopathy), a fatal, transmissible neurodegenerative disease that affects the central nervous system of cattle, was detected in Canada, primarily due to the relatively infrequent media reporting of BSE compared to concurrent news stories of other events such as SARS, WNV (West Nile virus), and U.S.-Iraq war (Lewis and Tyshenko, 2009). By contrast, Boyd and Jardine (2011) concluded that the risk of BSE in Canada was neither socially heightened nor attenuated through the social process. Local and social context gave rise to a public understanding of BSE related risk that indicated actual health and economic outcomes. This disparity between these two studies may be attributable to the fact that the former focused solely on the comparison of press coverage of BSE in Canada and other countries, while the latter incorporated various elements (e.g. media, cultural context, and trust) into its analytical structure.

Under some circumstances, non-governmental organisation (NGO) and scientific groups play a key role in attracting extensive public attention. In a debate between Greenpeace (the international non-governmental organisation) and Shell (multinational oil company) over a deep-sea disposal of the Brent Spar oil rig, Greenpeace carefully constructed and successfully diffused three potent risk signals including the toxic Spar, the reckless, polluting giant-Shell, and the moral sanctity of the deep ocean (Bakir, 2005). Greenpeace's direct action triggered a broad range of amplification stations including various media, governmental and non-governmental sectors, individuals, and subsidiaries of Shell, together with Shell's inadequate response, resulting in socially amplified risk of deep-sea disposal. Similarly, environmentalists portrayed the risk of a high-speed railway tunnel construction project via four risk signals (i.e. endangered species, the moral sanctity of nature, political distrust, and Jiyul and salamander-oneness) (Chung, 2011). They emphasized the negative impacts of the tunnel construction on the mountain ecosystem. The first signal addressed the seriousness of risks that would be caused by the construction and made the construction begin to attract nationwide attention including considerable media coverage and a special review committee organized by the President. The second signal strengthened the first one in that Friends of Salamander, an environmental organization, filed a lawsuit accusing the construction authority

of neglecting the role of salamanders as a symbol representing endangered species in that area, which aroused public concern and triggered legal and social controversies. The third signal placed a political burden on the President by way of connecting environmental protection with public trust in political leaders. As for the last signal, Jiyul, a leading activist in the fight against the tunnel construction, conducted a hunger strike lasting 100 days, which magnified public concern for the issue. These signals suggested an amplification process in which public concern spread out from local to national levels and perception of risk associated with the tunnel construction was heightened progressively with the sequential order of four risk signals.

Experts are also key actors in putting risk issues on the road to amplification or attenuation. Scientists at the Ramazzini Foundation over-stated their research result that aspartame, an artificial sweetener can cause cancer to human beings (Lofstedt, 2008). The Ramazzini research group generated great publicity and made aspartame an amplifiable topic mainly through active manipulation of press coverage, and ripple effects produced in this process prolonged the controversy unexpectedly. Among expert groups, general practitioners (GPs) are also thought to have a role in the social amplification process. According to Raude et al. (2004), French GPs' risk perception related to BSE tended to be amplified in their practice and to be attenuated in their own private circle. In other words, they were risk amplifiers for their patients and risk attenuators for members of their family. Furthermore, GPs were more proactive in advising their patients than they were to their family, given that precautionary advice provided by GPs to their patients was slightly more correlated to risk estimates, whereas their reported behaviours toward family members were better related to the degree of their expressed concern about BSE linked risks. This discrepancy can be explained from two aspects. First, the data that were collected for the study indicated reported, not observed, behaviours of GPs. Therefore, there was a good chance that respondents over-reported recommendations made to their patients and underreported those provided to family members. Second, as Kasperson (1992) argued, 'Individuals in groups and institutions do not react merely in their roles as private persons, but rather according to the role specification associated with their positions. Amplification may therefore differ among individuals in their roles as private citizens and in their roles as employees or member of social groups or organizations'. Thus, GPs acted more 'scientifically' with their patients and more 'parentally' with their family.

Given the diversity of findings about SARF, it is important to bear in mind that the selection and the representativeness of samples, the data collection methods, and the focal points of the research will affect the outcome to some degree. In some cases, the sampling of respondents and risk events is highly specific or selective (Burns et al., 1993; Busby and Duckett, 2012; Chung, 2011; McComas, 2003; Renn et al., 1992). A considerable number of studies rely on cross-sectional data, which allows researchers to explore associations among

various variables, but not necessarily the causality of observed phenomena (Binder et al., 2011; Loewenstein and Mather, 1990; Smith et al., 2013; Yeo et al., 2014). The analytic focus of one study usually far outweighs potential concerns about other research questions, so some critical features of the phenomena may not be taken into account when researchers are committed to look at a single issue at a single point (Binder et al., 2011), making it unlikely it can examine other important hypotheses (Burns et al., 1993).

## 2.2.2 Contributory effects

Research on risk amplification provides evidence that multiple sources of information and interactions affect the way individuals think about, and respond to, risks. Apart from media and non-media actors, other factors can also serve to trigger public attention to a particular risk and increase risk perceptions.

Kasperson (2012) pointed out that *social trust* is an important element of the dynamics of social amplification. Some research results provide support for the notion that trust in how regulatory institutions cope with a risk event influences risk perceptions. Boyd and Jardine (2011) showed that the general public indicated a high level of trust in government after BSE was detected in Canada. This trust was fostered by Canadian news media, which provided accurate depictions of risks associated with BSE and enhanced the public's confidence in the safety of beef products. This was one of the major factors that affected the general public's perceptions and contributed to the lack of amplification or attenuation of BSE related risks. But unlike the viewpoint of Boyd and Jardine (2011), the research by Frewer et al. (2002) proved that the media had no impact on individuals' trust in risk regulators with regard to the risks of GM food in the United Kingdom. A potential explanation is that trust in institutions was too low to decline further; in other words, a "floor effect" occurred. Trust and perceived risk independently influenced people's attitudes toward GM food. Higher levels of trust in regulators were interrelated with more risks and negative effects perceived by the lay public. Vila and Font (2008) found that loss of trust in the media in UK society made people more critical about information on genetically modified (GM) foods, impairing the role that the media played in shaping public risk perception. However, no conclusive evidence has been found that there is a direct cause-and-effect relationship between media specific biases and distrust in the media. Therefore, trust in the media does not appear to be an influencing factor of risk perception of GM food.

Some scholars have explored how *place attachment* affects the social construction of risks and drawn some interesting conclusions. A case study examined the controversy over the Alberta's Industrial Heartland (AIH) proposal that aimed at attracting investment by establishing large-scale petrochemical industry (Masuda and Garvin, 2006). The analysis

illustrated that risk perceptions were shaped by place-bound attachment as well as complex cultural worldviews regarding how people were affiliated to place. Individuals (mainly residents) who had a strong sense of belonging and strong emotional attachment to local community saw industrial encroachment possibly brought by the AIH proposal as a threat to their livelihoods. They regarded the region as a safe place to live and thereby perceived high risks surrounding the AIH proposal. Individuals (mainly non-residents, such as officials and industrial representatives) who acted to promote the AIH proposal believed that the region was suitable for industry and industrial development that would serve the interests of all residents. They viewed industrial development as an opportunity to boost the local economy (for example, create job opportunities and business spinoffs) and discounted the intrinsic dangers and uncertainties associated with the AIH proposal. Similarly, Cantrill (2011) presented the sense of self-in-place framework in the context of wildlife conservation, and suggested that place attachment to the environment could engender an amplification of the perceived impacts of conservation initiatives designed to protect and restore wildlife populations. A sense of self-in-place is used to clarify the relationship between identity and place, and a person's sense of self-in-place refers to two overlapping sets of cognitions (Cantrill and Senecah, 2001). One of these components deals with the connection between people and geographic venues (i.e., specific locations), and another involves an embedding of one's identity in larger, more general environment that emphasizes individual perceptions of and interaction with surroundings. In wildlife management context, for long-term residents of a target region, the sense of self-in-place bestowed a premium upon the use of landscape for social activities and outweighed the value of ecosystem services provided by biodiversity. Therefore, the public were likely to perceive wildlife conservation practice as threats to their long-standing lifestyles, resulting in heightened perceptions of risk about conservation projects.

It has also been found that *exposure to risk* is a fairly good predictor for individual responses to hazardous events (Renn et al., 1992). Data analysis indicated that exposure to risk was strongly related to perceived risk of hazards, and was more influential in shaping people's perceptions than were actual casualties or magnitude of property damage. As a consequence, an exposure of many people that brings about minor injuries or only a small number of casualties is more influential in shaping risk perception than that of a few people leading to several casualties (Renn et al., 1992).

Existing empirical work shows that *information sources* and *social interaction* could affect wildfire risk perceptions among homeowners living in a wildland-urban interface (WUI) (Smith et al., 2013). Residents who received information from expert source (local volunteer fire departments and state and federal forest service representatives) and nonexpert source (friends, family, and community groups) exhibited higher levels of perceived probability of a

wildfire, while those who had not received wildfire information from any source were likely to attenuate the probability that a wildfire would occur. Among a variety of interactions between community members, homeowners and their neighbours, and other social contacts, talking with neighbours about wildfire exerted the strongest positive impact on perceived probability of experiencing a fire, followed by attending a fire-specific event.

There are other theories that can help broaden the understanding of the mechanism by which amplification or attenuation occurs in the social arena. Of special significance are *social resonance theory* and *common pool theory*. Renn (2011) has applied these two analytical concepts to investigate the mechanism of amplification and attenuation in the climate change debate. Resonance theory states that subsections of society provide vital services to society as a whole through four major subsystems: economy, politics, the social sphere, and the cultural sphere (Parsons, 1951). Communication within a system is generally correlated to the resonance medium that it deals with. Communication between systems depends on successful transformation of messages from one dominant resonance medium to another. Resonance reflects the extent to which a sense of common understanding or concern is produced in the communication process within a system or between different systems (Renn, 2011). With respect to the threat of climate change, the impacts of global climate change resonate with concerns of each subsystem of society and urge these subsystems to work on solutions in terms of their own function. Resonance makes climate change a top issue in societal debates, attracting extensive public attention and intensifying the perception of risks of climate change.

Common pool resources are considered as open access resources for each individual (person or state), but unlimited access can cause overuse of resources (Paterson, 2009). It is argued that behaviour is not only partially driven by attitudes and motivations but also by social feedback such as someone else's comments on one's contribution. Moreover, common pool resources introduce free riders who take advantage of resources without paying the price. In the context of climate change, neither states nor individual persons have an incentive for taking proactive actions when they perceive others using resources without constraints or perceive the effectiveness of their actions as marginal (Renn, 2011). Furthermore, free riders may obtain benefits at the cost of those who take effective actions. This dilemma makes actors downplay the significance of their actions and leads to an attenuation of the climate change risks.

## 2.2.3 The different contexts in risk amplification

Existing empirical work on social risk amplification focuses on hazard events that occur in a wide range of contexts. Basically, these risk events can be classified from two dimensions:

*risk bearer* and *risk agent*, as shown in Table 2.1. Risk bearers refer to *human* and *environment*. Risk agents include natural risk, technological risk, and social risk. Specifically, *natural risk* involves tunnel construction (Chung, 2011), waste landfill (McComas, 2003), wildfire risk (Smith et al., 2013), deep-sea disposal of an oil rig (Bakir, 2005), oil spills (Leschine, 2002), wildlife conservation (Cantrill, 2011; Hart et al., 2011), chemical accidents (Souza Porto and Freitas, 1996), industrial heartland amendment (Masuda and Garvin, 2006), fishing and fish consumption (Burger, 2000), and earthquake (Stanciugelu, 2013). *Technological risk* refers to site-selection of a biological research facility (Binder et al., 2011), site-selection of nuclear weapons facilities (Metz, 1996), nuclear power risk (Yeo et al., 2014), oil spills (Leschine, 2002), and genetically modified foods (Frewer et al., 2002; Vila and Font, 2008). And *social risk* concerns MMR (measles, mumps and rubella) vaccination (Petts and Niemeyer, 2004), an oral contraceptive pill scare (Barnett and Breakwell, 2003), aspartame scare (Lofstedt, 2008), BSE (Boyd and Jardine, 2011; Lewis and Tyshenko, 2009; Raude et al., 2004), and zoonotic diseases (Busby and Duckett, 2012). Based on SARF, these studies largely review the dynamic process in which risks are either amplified or attenuated by different groups, and the divergence between expert judgment and the lay public's beliefs about the magnitude and the controllability of risks.

Table 2.1 Classification of risk events in two dimensions

| Risk bearer | Risk agent | | |
|---|---|---|---|
| | Natural risk | Technological risk | Social risk |
| Human | Earthquake | Nuclear power risk | MMR vaccination |
| | Chemical accidents | Genetically modified foods | Aspartame scare |
| | Industrial heartland amendment | Site-selection of weapon facilities | An oral contraceptive pill scare |
| | Fishing and fishing consumption | Site-selection of a biological research facility | BSE |
| | | | Zoonotic diseases |
| Environment | Oil spills | Oil spills | |
| | Wildfire risk | Nuclear power risk | |
| | Waste landfill | Genetically modified foods | |
| | Tunnel construction | | |
| | Wildlife conservation | | |
| | Deep-sea disposal of an oil rig | | |

The way by which risks are distorted is significantly different across different risk contexts. Some studies provided excellent examples of how risks were misinterpreted on account of particular scenarios. In so far as site selection of a biological research facility was concerned, residents in five potential communities for a new biological research facility were actively encouraged to express their thoughts and participate in decision-making process (Binder et al.,

2011), and this provided an ideal context for examining the role that interpersonal discussion played in influencing individual judgments of risks. As another example, an eco-industrial development proposal in Alberta, Canada (Masuda and Garvin, 2006) brought industrial risks into public view and clashed with residents' sentiments that the target region was a safe place to live, making place attachment the primary influencing factor for risk amplification. With respect to other risks, especially natural disasters such as earthquake (Stanciugelu, 2013) and some threats to life such as BSE (Boyd and Jardine, 2011; Lewis and Tyshenko, 2009) and genetically modified foods (Frewer et al., 2002; Vila and Font, 2008), media coverage was the most influential on people's overall evaluation of risks and therefore received widespread attention.

In principle, there are two possible explanations for why risk amplification varies so much between particular contexts. First, as risks are situated within the social experiences and interactions between individuals and social groups (Scherer and Cho, 2003), the social context in which risks are embedded and the ways in which risks are communicated contribute to shaping risk perceptions, leading to unique findings about patterns of risk amplification from risk to risk. According to SARF (Kasperson et al., 1988), the social, institutional, and cultural contexts in which the risk information is appreciated and diffused endow the information with specific meanings and values that only make sense within the socio-cultural contexts. Thus, how the general public or social groups interpret and react to information about risks or risk events depends largely on the roles they occupy, the experience they have, the beliefs or rules they comply with, and the extent to which their judgments are affected by various social stations in the particular social settings in which risks or risk events occur.

Second, risk debates of different domains involve fundamentally different agents that act as risk amplifiers or attenuators. For example, environmental risks are probably of particular interest of environmental organizations, governmental agencies, social activists, NGO (non-governmental organisation) as well as the media, and human diseases associated with vaccination, medication and food consumption are more likely to be the top concern of GPs, the department of health, scientific institutions, and also the media. The degree and the pattern of influence imposed by the agents on public risk perception might be distinctive in terms of different risks, given that their stance on the risk issue depends on their social status in that event. Take the media for example, media coverage may be the major information source available for the lay public in certain risk events, so the media bears principle responsibility of facilitating risk amplification or attenuation, while for some other risk events, the frequency and content of media reporting depend on what the media passively receives from experts or regulatory institutions, which suggests a diminished role for the media in shaping risk perception.

A role is also played by whether risks are seen as natural or man-made. It may be that natural processes cannot be improved by cautious and proactive actions, so once a natural accident occurs, people conclude it is in fact inevitable (Leschine, 2002), while people usually believe that manmade damage could have been avoided by more prudent behaviour, or by better knowledge and experience about the risk (Schmidt, 2004). At present, there is actually no strong evidence to support the hypothesis that people are more apt to amplify human caused risks, but this is definitely an important question that merits comprehensive investigation in future research.

Finally, there is an obvious difference in the risks of accidental or chance hazards and those of deliberate harm like terrorism. Terrorism is a criminal act that produces widespread fear and panic among the public beyond the immediate victims and has become increasingly common throughout the world. The general public, victims, the government, the media, and other organizations are normally involved in terrorism, and their responses are broad in scope. There have been some studies on risk perceptions about terrorism (Lee and Lemyre, 2009; Lemyre et al., 2006; Lerner et al., 2003; Rogers et al., 2007; Sönmez and Graefe, 1998), but few within the social amplification of risk framework.

## 2.2.4 The different methodologies by which risk amplification has been studied

In general, there are two main methodologies applied to empirical work on social risk amplification: case study and survey. Table 2.2 shows the two methodologies in terms of data collection method and data analysis procedure.

Table 2.2 Methodologies used in empirical work

| | Methodology | |
| --- | --- | --- |
| | Case study | Survey |
| Data collection method | Interview (3) | Face to face survey (3) |
| | Media coverage (3) | Online survey (1) |
| | Group discussion (1) | Telephone survey (3) |
| | Quasi-experimental design (1) | Mail survey (2) |
| | Focus groups and interviews (1) | Mail survey and online survey (1) |
| | Data from past and ongoing work (1) | Focus group interview (1) |
| | Media coverage and secondary data from surveys (1) | Media coverage (2) |
| | | Mixed methods (2) |
| Data analysis procedure | Media content analysis (4) | Ordinary least-squares (3) |
| | | Linear probability model (1) |
| | | Structural equation model (1) |
| | One-way analysis of variance | Partial least squares (1) |

| | (1) | Covariance structure analysis (3) |
| --- | --- | --- |
| | | Principal components analysis (2) |
| | | Media content analysis (2) |

Note: figures in brackets indicate the number of articles using that method.

## *Case study*

Most case studies are qualitative in essence, applying SARF to analyse the reaction mode of different social stations by means of interviews (Barnett and Breakwell, 2003; Lofstedt, 2008; Masuda and Garvin, 2006), group discussions (Petts and Niemeyer, 2004), media content analysis (Barnett and Breakwell, 2003; Chung, 2011; Lofstedt, 2008), focus groups and individual interviews (Busby and Duckett, 2012), and media content analysis and secondary data from surveys (Vila and Font, 2008). For example, Chung (2011) used the volume of readers' comments on online newspaper articles and the number of visits to message board posts as indexes to demonstrate the level of public concern for environmental risks from a high-speed railway tunnel construction project in South Korea. Petts and Niemeyer (2004) employed two-phase interactive discussion groups (at the first meeting groups examined preferred sources of health information, and at the second meeting groups focused on perceptions of the information) to observe lay talk about risk issues of MMR (measles, mumps, and rubella) and to explore how experience, mediated knowledge, and social context influence public perceptions of risk. A study on risk perception of eating fish derived data from four published studies and one ongoing study and conducted a meta-analysis to gather in-depth information (Burger, 2000). Vila and Font (2008) used both media coverage and data from Eurobarometer surveys to examine the relationships between the content and intensity of press media and risk perceptions of new genetically modified (GM) foods between 1999 and 2004 in Spain and the United Kingdom. These qualitative studies have suggested how practical knowledge, experience, and personal context of individuals affect their attitudes toward a risk issue, and how particular actors such as scientists, environmentalists, experts, governmental agencies, and NGO take advantage of mass media to voice their opinions and to affect the public's perceptions of risk.

Quantitative case studies on risk amplification have been quite limited to date. In an embedded case study, a quasi-experimental design was adopted to capture the effects of public meeting attendance on risk perceptions at three data collection points, with questionnaires mailed to attendee and nonattendee samples (McComas, 2003). Survey questions were analysed using one-way analysis of variance (ANOVA) to examine the relationship between attendance at public meetings and tendency to amplify or attenuate risk.

## *Survey*

The survey strategy has also gained broad popularity in the field of risk research, and the forms of survey have been wide-ranging: face to face survey (Burns et al., 1993; Frewer et al., 2002; Renn et al., 1992), online survey (Yeo et al., 2014), telephone survey (Boyd and Jardine, 2011; Hart et al., 2011; Stanciugelu, 2013), mail survey (Binder et al., 2011; Raude et al., 2004), and an exception of combining both mail survey and online survey (Smith et al., 2013). As expected, questionnaire was the most widely used approach to collect data by survey strategy, but focus group interview (Petts et al., 2000), where standard questions are asked of all interviewees (Saunders et al., 2003), and content analysis of media reporting related to risky subjects (Lewis and Tyshenko, 2009; Petts et al., 2000), also fell into this strategy.

Data collection sometimes needs to rely on not simply one method, but a series of methods, especially for some of the more complicated studies aimed at shedding new light on the causal relationships among various dimensions of a risk event. For example, both Renn et al. (1992) and Burns et al. (1993) adopted a mixture of public survey, expert rating, individual rating, news coverage search, and iterative Delphi procedure to gather data regarding five dimensions that were believed to contribute to risk amplification: physical consequence, risk perceptions, media coverage, public responses, and societal impacts. Since each dimension was measured by different variables, different approaches were required to operationalize them. More specifically, physical consequences were estimated by expert rating, risk perceptions and risk responses by surveying university students and individual rating, media coverage by keyword search, and societal impacts by Delphi panel. The use of multiple, but independent methods to obtain data provides more perspectives on the research problems being investigated and improves the credibility and generalizability of results (Smith et al., 2012).

In survey research on SARF, selected variables were generally measured by asking respondents (individuals or experts) to rate corresponding questions on different scales. The correlations between risk perception and influencing factors, which were the purpose of almost all quantitative studies, were statistically tested through regression analysis at large. In particular, these factors include the volume and content of media reporting (Frewer et al., 2002; Lewis and Tyshenko, 2009), cultural and social context and media coverage (Boyd and Jardine, 2011), interpersonal discussion (Binder et al., 2011), environmental values and media use (Hart et al., 2011), and social interaction, personal characteristics, and information sources (Smith et al., 2013). And the regression methods include hierarchical ordinary least-squares (OLS) (Binder et al., 2011; Smith et al., 2013; Yeo et al., 2014), linear probability models (Boyd and Jardine, 2011), structural equation modelling (SEM) (Hart et al., 2011), partial least squares (PLS) (Burns et al., 1993), and covariance structure analysis (Burns et al., 1993; Frewer et al., 2002; Renn et al., 1992).

Generally speaking, selection of statistical tools is subject to what particular results are expected to get out of the analytic framework. Specifically, OLS was used to regress risk perceptions against expected correlates, such as demographic differences, information sources, social interactions, personal characteristics, benefit perception, predispositions, and news media attention, so as to determine their explanatory power to risk perceptions. It is worth mentioning that two studies performed principal components analysis (PCA) to create subscales of variables indicating the changes in risk perception and facilitate subsequent analyses. For example, Frewer et al. (2002) extracted three subscales (risks and negative effects, trust and choice, and benefits) from 53 attitude items, with each subscale composed of representative items. Smith et al. (2013) used PCA to compress variables into perceived probability and perceived consequence based on the hypothesis that social amplification has different impacts on these two dimensions of risk perception.

## *Summary*

As suggested above, empirical work on risk amplification has presented comprehensive evidence that risk perceptions are often distorted by comparison with expert judgments, and that public response is usually stimulated and modified to an unexpected degree, because a number of influencing factors including social stations and other factors exaggerate or weaken public concern for risk. These distortions, to some extent, reflect the influence of interpersonal communication on the individual level and the nature of social interaction on the social level.

By and large these studies seek to identify the causal relationships and fundamental laws that can interpret regularities in risk amplification, but they fail to probe into the mechanism for amplifying or attenuating risk, which is normally considered the core of risk amplification and also essential for modelling risk amplification. They are mostly concerned with what factors are correlated with amplification, rather than with the processes that produce amplification. Another limitation is that little effort has been made to explore variations in public behaviours especially across different regions or risk contexts. The effort involved in investigating risk amplification in any particular context makes it hard to carry out comparative studies across different contexts, so it can be unclear what is general and what is particular in each study.

## 2.3 Modelling of risk amplification

So far there have been very few papers on modelling of risk amplification, and they have employed both system dynamics and agent-based models. For example, Burns and Slovic (2007) developed a system dynamics model of amplified perceptions of risk of terrorism to

capture factors critical to forecasting public response to a terrorist attack. The diffusion of fear within a community was modelled and simulated in the context of three hypothetical disaster scenarios (anthrax attack, bomb blast, and propane tank explosion) to illustrate how risk perceptions and behavioural responses shifted with factors such as characteristics of hazardous events, media coverage, word of mouth, and community intervention. Busby and Onggo (2013) developed a system dynamics model to examine whether risk perceptions of different social actors would diverge in the context of zoonotic disease outbreaks. Their model was based on the notion that social risk amplification is a subjective attribution and incorporated three attributional elements: confusion, distrust, and perceptions of the significance of behaviour change. Both Busby et al. (2016) and Onggo et al. (2014) have used an agent-based model to explore the mechanisms of social risk amplification. Busby et al.'s (2016) model focused in particular on some central characteristics of risk responses: the way actors anticipate each other's biases, the way actors change their beliefs as the prevalence of a risk perception varies, and the way risk communications are fashioned on the basis of responses to previous communications. Onggo et al. (2014) modelled both narrowcast communication through social networks and broadcast communication through media to look at how they contribute to the formation of public risk perception. In addition, Bleda and Shackley (2012) used simulation modelling as an analytical tool for appreciating the formation of perceptions of risk associated with BSE. They modelled two types of risk amplification: amplification caused by media coverage and amplification caused by other forms of social communication such as the communication in the social networks and the official public communication of new scientific discoveries.

It is evident that these studies help achieve a better understanding of the dynamics of public perceptions of risk and provide useful implications for risk managers and policymakers. More importantly, they are also trying to work out the mechanism of social risk amplification based on indications from prior empirical work. However, there have also been some basic limitations of this modelling. To begin with, it is difficult to have access to plausible data of some critical variables in the model (Busby and Onggo, 2013). This is the case in the work of Bleda and Shackley (2012), Busby and Onggo (2013), and Busby et al. (2016). Second, all these studies, as Busby and Onggo (2013) pointed out, 'concentrate specifically on the risk amplification phenomenon to the exclusion of the many other processes that, in any real situation, risk amplification is connected with'. A lot more empirical evidence or potentially important factors needed to be incorporated into the model based on corresponding assumptions about risk amplification. Third, many of the nonlinear relationships between model variables are drawn upon subjective judgments (Burns and Slovic, 2007). A more objective evaluation with reliable data would probably provide valuable new insight into the phenomenon.

There seem to be two main reasons why more progress has not been made in modelling SARF. First, the definition of risk amplification is still vague. It is normally assumed that risk amplification should be a gap between different risk judgments, but there is considerable controversy about what gap social risk amplification refers to. Is it the gap between expert and public assessment of risk, or between objective (real) and subjective (perceived) risk? It seems hard to determine the baseline risk and the deviation of risk perception due to ambiguous definition of social risk amplification, making it more complex and debatable to model risk amplification.

Second, data required for modelling is often difficult to collect. Given that social risk amplification involves internal feedback loops linking risk responses with behaviours that in turn modify risk perception, system dynamics is deemed a natural choice to show the dynamics and reflective nature of social behaviour following a risk event. Nevertheless, system dynamics relies heavily on quantitative or qualitative data to establish and simulate feedback models, and it draws upon a much broader set of data than do traditional statistical analytic tools (Luna-Reyes and Andersen, 2003).

## 2.4 Conclusions

This survey leads to several points that can be drawn from the social risk amplification literature.

First, although there have been some criticisms of SARF, such criticisms have not stopped SARF being an influential framework employed by academics, risk managers, and policymakers. The original article (Kasperson et al., 1988) explicitly pointed out that 'there is no such thing as "true" (absolute) and "distorted" (socially determined) risk'. The authors acknowledge that amplification is exclusively linked to negative impacts, and the degree of amplification or attenuation influences the extent to which the ripple effects are created by social responses (Kasperson and Kasperson, 1996). The relationship between physical consequences of risk events, press coverage, public responses, individual layperson perceptions, and societal impacts is still ambiguous, even conflicting across studies (Busby and Duckett, 2012). But this problem does not undermine the basic role of SARF to provide a general terminology and framework for social risk responses that will need adapting to particular contexts. The notion that there is a risk that becomes distorted socially makes SARF attractive at both theoretical and practical level (Duckett and Busby, 2013; Renn et al., 1992).

Second, the media plays multiple and sometimes conflicting roles in the risk debate (Kasperson and Kasperson, 1996). It is not always the case that the media either makes risks seem disproportionately large or oversimplifies the complexity of risks. The literature

indicates that the media can serve as an amplifier, an attenuator, or an impersonal narrator of risk (Boyd and Jardine, 2011). To some extent, this may be explained by the specific social and cultural context in which risks or risk events occur. As far as non-media actors (for example experts, NGO, and scientific institutions) are concerned, the ways by which they trigger public concern and shape risk perception are significantly different. In certain circumstances, factors such as trust, place attachment, information sources, and social interaction play a role in accounting for exaggerated or diminished perceptions of risk.

Third, risks of different contexts become amplified or attenuated in markedly different ways. One reason lies in the social context in which risks are embedded and the way in which risk information is transmitted. Another reason is that agents entering into different contexts are apparently different and tend to act on their own positions and interests in accordance with the particular context.

Fourth, the methods used in empirical studies are wide-ranging, and generally these studies have been concerned with the causal relationships between elements within the social amplification of risk framework. The findings suggest predictors of behavioural intentions of individuals but say little about the dynamics underlying the risk amplification process in various situations.

Fifth, the modelling of risk amplification has been quite limited to date, because the definition of risk amplification is far from clear and there is a lack of access to necessary data. But correspondingly these are also reasons to do much more modelling. The vagueness about definition is something that models force us to resolve, and the process of modelling helps us realise where definitions and specifications of amplification mechanisms are vague. And the absence of data may only become apparent when building models reveals a need for data that we do not have.

Sixth, the question about which risks are more likely to be amplified by the general public is currently unknown. It seems that events caused by nature such as earthquake and wildfire risk are more acceptable than those by human such as environmental risk, technological risk, and threats to human life. Until now, there is actually no strong evidence to support the hypothesis that people are more apt to amplify human caused risks, but this is definitely an important question that merits investigation in future research. In addition, empirical evidence presented in the literature demonstrates that SARF is applicable to a broad range of risk events, but there may be certain risks of other domains that have not been probed into by scholars, such as counterfeiting and terrorism.

Finally, the role that organizational decision making plays in shaping risk perception deserves attention. It has been demonstrated that perceived managerial incompetence influence public risk perception to a greater extent than does the number of casualties (Burns et al., 1993). Although traditional use of SARF generally examines risk amplification at the

social level, decision making of the organization involved in a risk event is relatively downplayed, or even neglected. For example, within studies on risks such as BSE, aspartame scare, contraceptive pill scare, and genetically modified foods, there are almost no discussions about the reaction of the organizations, how they make decisions to affect public perception, and how they interact with the public and the media.

The aim of this study is to explore some of these issues in the context of product recall. In particular, the aim is to develop a more precise understanding of the mechanisms underlying SARF through modelling. This also forces us to define what we mean by 'amplification', and it forces us to think about what aspects of the amplification process are general and what are contextual. As a model of product recall, it will also require a specification of what actions an organization takes and how these are responded to by public consumers. And it will enable the exploration of the effects of the media adopting different roles during a risk event.

# 3 RESEARCH CONTEXT

Product contamination events vary from one case to another in terms of risk agent, actors involved, management strategies, societal risk responses, and potential consequences. In order to better understand risk perceptions around product contamination crises, it is essential to select a specific case that captures a typical social process of risk amplification as a reference case for this study. The purpose of this chapter is to look at a context within which the problem situation resides, and the model is subsequently developed with this context in mind.

This chapter presents three product harm crises in China that had triggered extensive public concern – the 2008 Chinese milk scandal, the Nongfu Spring water event, and the 'gutter oil' scandal. China represents an interesting setting for a risk amplification study because it is a country in which there is still strong state control over organizations, and particularly over the dissemination of news about organizations, misconduct and hazardous events. Yet it is also a country in which there is a growing consumer culture and increasing expectations about high product quality and safety. There are other product contamination scandals that had sparked fears among consumers, besides the three considered in this chapter, but are not considered here, such as toxic bean sprouts (bean sprouts tainted with illegal additives such as urea, enrofloxacin, antibiotics, and 6-benzyladenine) (Global Times, 2011a), 'cadmium rice' (rice contaminated with heavy metals including cadmium) (Tatlow, 2013), glow-in-the-dark pork (pork contaminated by phosphorescent bacteria) (Lodish, 2011), leather milk (milk tainted with hydrolyzed leather protein) (Foster, 2011), and so on. Those scandals arose in certain areas in China and did not evolve into nationwide crises. In contrast, the three events covered in this chapter had a much larger sphere of influence, involved relatively clear interactions between different actors, and caused much stronger social reactions. In Chapter 5 where the model development is described, it will be apparent that the first of these events is the prototype case for the agent model in this study. However, describing all three cases helps to bring out what is common and what is different between different product contamination crises, and it helps clarify the reasons for choosing one of the cases as the prototype for the modelling. The point of ABM is to model dynamics over time, so it becomes important to show the chronology of actual cases. The descriptions of a particular risk event provide a broad idea of how the event progressed and do not cover all the details presented in the chronology.

## 3.1 2008 Chinese milk scandal

In September 2008, an adulterated milk scandal was unfolded in China. It was discovered that Sanlu Group, a major player in the dairy industry in China, was adding melamine to artificially enhance the protein readings in baby milk powder (Xinhua News Agency, 2008a). Melamine is a colourless crystalline chemical used in making plastics. It could cause infants to develop kidney stones and other renal and urinary failure. The chemical was also found in baby formula products produced by 21 other companies (Yardley and Barboza, 2008). By November 2008, China reported an estimated 300,000 victims (Branigan, 2008), with six infants dying from kidney stones and other kidney damage and about 54,000 babies hospitalised (McDonald, 2008). The melamine milk crisis was called by the World Health Organization one of the largest food safety events it had to deal with in recent years (Schlein, 2008).

New Zealand dairy cooperative Fonterra, which owned a 43% share in Sanlu, said it was alerted to melamine contamination on 2 August (Ramzy and Yang, 2008). Fonterra immediately urged a full public recall of the milk powder, but Chinese authorities refused. On 11 September, Sanlu launched a recall of all of its milk powder products made before 6 August (Ramzy and Yang, 2008; Xinhua News Agency, 2008b). And the following day, on 12 September, China's Ministry of Health announced a nationwide investigation into the milk scandal. On 15 September, the company issued a public apology for the tainted milk powder (Li, 2008). During the crisis, Sanlu attempted to cover up the contamination. A memo leaked by a Sanlu staff member on 12 September said that Sanlu paid Baidu, China's leading search engine, 3 million yuan ($640,000) for screening all negative news from search results (Welford, 2008).

Ever since the tainted milk affair broke, the central government had ordered the media not to report any negative news disturbing the Beijing Olympics (Morillon, 2008; Spencer and Foster, 2008). Censorship was imposed to suppress bad news about the contaminated milk scandal – the media was ordered to adhere to the official line provided by state news organizations such as Xinhua News Agency and the People's Daily (Mooney, 2008). Moreover, blogs were blocked, and sensitive subjects and keywords related to the milk scandal were forbidden on the Internet (Morillon, 2008). Jiang Weisuo, who exposed milk contamination in 2006, died from knife wounds on 12 November 2012 (Zhuang, 2012).

The situation that China is averse to negative news of any sort had not changed much over the course of this incident. The central government's continued involvement in the flow of information was one of the main reasons why many consumers were ill-informed about the causes and severity of the contamination as well as the extent of recalls (Chen, 2009; Morillon, 2008; Yardley and Barboza, 2008). The milk crisis caused anger and resentment towards milk

producers and sparked serious concern and panic among the population. Consumers had severely lost confidence and trust in the dairy industry and in the supervision of food safety in China, and thus their demand for locally produced infant formula was greatly lessened (Financial Times, 2008; Hatton, 2013). Most consumers have lost trust in local brands and have been seeking to purchase baby milk powder imported from other countries and regions such as New Zealand (Tahana, 2008) and Hong Kong (Jacob, 2013; Pomfret, 2011; So, 2008). Moreover, at least 25 countries imposed specific bans on Chinese dairy products because of the melamine contamination (The New York Times, 2008).

Table 3.1 provides the chronology of the Sanlu milk contamination case.

Table 3.1 Chronology of Sanlu milk scandal

| Date | Progress |
|---|---|
| 01/08/2008 | Tests showed that 15 out of 16 batches of Sanlu baby formula contained potentially poisonous levels of melamine.<br>The chairman of Sanlu, Tian Wenhua, ordered a cover-up of the contamination. |
| 02/08/2008 | Fonterra was alerted to melamine contamination. |
| 9/09/2008 | New Zealand Embassy in Beijing informed the Chinese government of the crisis.<br>News reports about the contamination began circulating in China. |
| 10/09/2008 | The scandal broke internationally by Reuters. |
| 11/09/2008 | Shanghai's Oriental Morning Post published a report stating that fourteen infants were diagnosed with kidney stones after consuming Sanlu milk powder.<br>Sanlu announced a nationwide recall of its baby milk powder. |
| 12/09/2008 | Sanlu Group admitted that its powdered milk was tainted with melamine.<br>China's Ministry of Health launched a nationwide investigation into melamine contamination. |
| 13/09/2008 | Sanlu halted production.<br>Nineteen people were arrested in connection with the tainted milk scandal. |
| 15/09/2008 | Two babies had died from contaminated milk.<br>Sanlu issued a public apology for the tainted baby milk powder. |
| 16/09/2008 | Powdered milk from 22 Chinese companies was found to be melamine-contaminated. Sanlu recorded the highest levels of contamination among all the samples tested. |
| 19/09/2008 | Melamine was found in liquid milk from three well-known companies: Mengniu, Yili, and Bright Dairy. Mengniu recalled all its products. |
| 23/09/2008 | About 54,000 children were sickened and four had died.<br>A number of countries had imposed blanket bans on Chinese milk products. |
| 24/09/2008 | Fonterra announced that it had written down the carrying value of its investment in Sanlu by 70 per cent. |
| 25/09/2008 | The European Union banned imports of baby food containing Chinese milk. |
| 9/10/2008 | Chinese officials insisted that the melamine contamination had been "accidental". China's Ministry of Health and four other government agencies issued a joint statement that set the legally acceptable level of melamine at 1ppm (1mg/kg) for infant formula and 2.5ppm for other dairy products. |
| 1/12/2008 | China's Ministry of Health revised the number of victims to nearly 300,000 with 51,900 hospitalised. |

| 25/12/2008 | Shijiazhuang court accepted a creditor's bankruptcy petition against Sanlu. |
| 02/01/2009 | A website created by individuals protesting against Sanlu was blocked by Chinese authorities. |
| 22/01/2009 | The Intermediate People's Court in Shijiazhuang sentenced Tian Wenhua, chairman of Sanlu, to life in prison. |

Sources: Branigan, 2008; BBC News, 2010; Chen, 2009; Li, 2008; Morillon, 2008; Ramzy and Yang, 2008; Reuters, 2008; Smith and Waldmeir, 2008; Spencer and Foster, 2008; Welford, 2008; Xinhua News Agency, 2008a; Xinhua News Agency, 2008b; Yardley and Barboza, 2008

Figure 3.1 shows a Google Trends plot of this crisis. This indicates the relative volume of uses of the search term 'Chinese milk scandal' over the relevant period. It shows a very large peak shortly after the crisis first broke, and a continuing much lower level of concern after this point. This continuing level of concern fluctuates quite sharply and goes to zero at some point. A series of specific, independent events are marked on the plot and listed below it, but these events do not necessarily coincide with particular features on the plot and are shown just to indicate points of development in the crisis. As suggested by SARF (Kasperson et al., 1988), significant crises are not just single events, but involve substantial 'ripple' events that follow directly or indirectly from some initial risk event. This plot is produced by Google Trends based on a specific search term (i.e. Chinese milk scandal), so there is no particular reason for labelling the events from H to A.
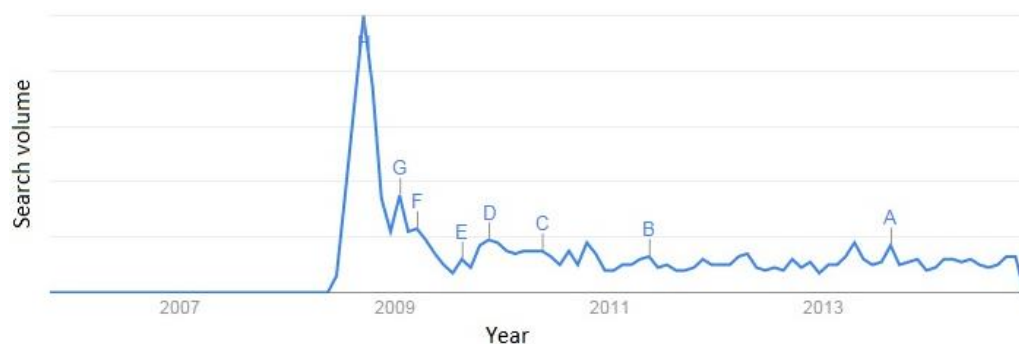


A: Fonterra moves to curb China baby milk scandal

B: Tainted milk scandal spreads to U.S. candy

C: Chinese parents seek damages over milk scandal

D: First civil lawsuit starts in China milk scandal

E: Two executed for roles in tainted milk scandal

F: China court upholds five sentences in milk scandal

G: Two sentenced to death over China melamine milk scandal

H: China milk scandal hits Japan firm, Taiwan

Source: Google Trends (2014). *Search term: Chinese milk scandal*. Available at:
https://trends.google.com/trends/explore?q=chinese%20milk%20scandal [Accessed 6 December 2014].

Figure 3.1 Google Trends of Chinese milk scandal

## 3.2 Nongfu Spring water event

The issues centred on product quality and production standard of bottled water produced by Nongfu Spring, one of China's largest bottled water suppliers. Consumer complaints about quality problems had been reported since March 2013 – when unidentified substances were found in the bottled water (Xinhua News Agency, 2013). The media raised the question of pollution in the water source. However, Nongfu Spring argued that the garbage near the water source had no impact on water quality and emphasized that temperature changes sometimes produced mineral salts in the bottled water (Global Times, 2013).

On 10 April 2013, the Beijing Times accused the company of intentionally adopting the water quality standards set by Zhejiang province that did not meet the national standards (Wang, 2013). Zhong Shanshan, chairman of Nongfu Spring, stated at a press conference that the criteria the company complied with was higher than the national levels, while the Beijing Times insisted reports about the water quality had been 'factual' and 'well-grounded' (Xinhua News Agency, 2013). Beijing quality watchdogs started an investigation into quality standard of Nongfu Spring water and temporarily suspended its production of barrelled drinking water in Beijing (Shanghai Daily, 2013). In the campaign the Beijing Times published 76 articles on 67 pages over 28 consecutive days criticising the water quality of Nongfu Spring (Global Times, 2013). In early May the company sued the Beijing Times over defamation, claiming that its reputation had been seriously damaged and demanding 200 million yuan (US$32.8 million) in compensation (Lu, 2013). At the same time, the newspaper launched a countersuit and demanded a public apology and symbolic compensation of 1 yuan from Nongfu Spring. An online survey on East Money website showed that 69% of respondents believed that the standards Nongfu Spring followed was below the national tap water standards, and that 86.9% of respondents would be reluctant to buy the company's bottled water.

The chronology of the Nongfu Spring quality crisis is given in Table 3.2.

Table 3.2 Chronology of Nongfu Spring water event

| Date | Progress |
|------|----------|
| 08/03/2013 | A customer complained about unidentified black substances in the bottled water produced by Nongfu Spring. |
| 11/03/2013 | Another customer made a complaint about red flotage in Nongfu Spring water. |
| 15/03/2013 | Nongfu Spring responded that the substances found in the bottled water were precipitation of mineral elements. |
| 25/03/2013 | A media report released that Nongfu Spring water intake was covered with all kinds of floating garbage. |
| 12/04/2013 | The Beijing Times accused Nongfu Spring of adopting a standard set by Zhejiang province that was below the national water quality standard. |

| | |
|---|---|
| 15/04/2013 | Nongfu Spring claimed that its quality indexes in a number of elements were stricter than the national levels. |
| 20/04/2013 | Beijing quality watchdogs started an investigation into Nongfu Spring and temporarily suspended its production of 19-liter barrels in Beijing. |
| 04/05/2013 | Nongfu Spring filed a lawsuit over the defamation of the Beijing Times. The Beijing Times launched a countersuit. |
| 06/05/2013 | Zhong Shanshan, chairman of Nongfu Spring, stated at a press conference that the company's products met or even exceeded the national standards. |
| 04/11/2013 | Nongfu Spring submitted a petition to the National Office Against Pornographic and Illegal Publications to hit back the 'false' reports of the Beijing Times. |

Sources: Global Times, 2013; Lu, 2013; Shanghai Daily, 2013; Wang, 2013; Wang and Yan, 2013; Xinhua News Agency, 2013

The Google Trends plot is shown in Figure 3.2. This shows search volume using the term 'Nongfu Spring water'. As with the Sanlu case, there is a strong early peak, followed by a fluctuating residual volume of concern. But there is a small peak before the strong early peak, indicating that the social amplification process is somewhat different. The earliest events in the crisis suggested some problem, but they did not immediately suggest a major problem. This arose shortly afterwards.
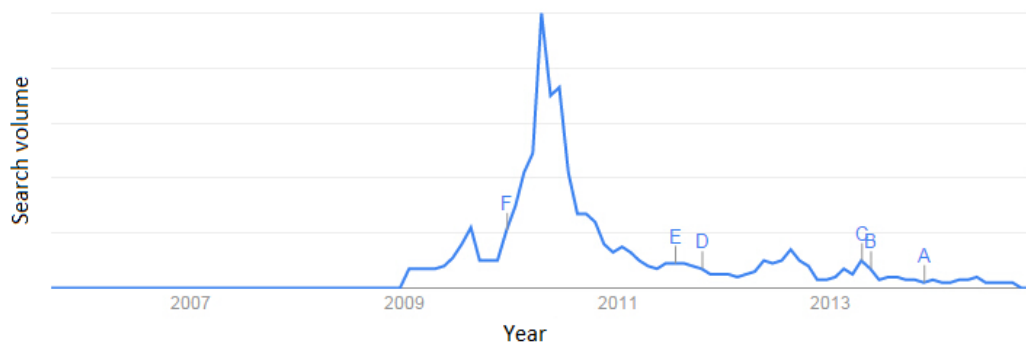


A: Beijing court hears Nongfu Spring defamation suit

B: Nongfu Spring to sue the Beijing Times over quality claims

C: Nongfu Spring to sue C'estbon over quality claims

D: Coca-Cola accuses Nongfu Spring of copying its design

E: 'It never happened' says Nongfu Spring in response to worm egg charges

F: 'It never happened' says Nongfu Spring in response to arsenic charges

Source: Google Trends (2014). *Search term: Nongfu Spring water*. Available at:

https://trends.google.com/trends/explore?q=nongfu%20spring%20water [Accessed 6 December 2014].

Figure 3.2 Google Trends of Nongfu Spring water event

## 3.3 Gutter oil scandal

'Gutter oil' is a term used in mainland China, Taiwan, Hong Kong, and Macao to describe illicit cooking oil that is produced by refining waste oil collected from restaurant fryers, sewer drains, grease traps, and slaughterhouse waste (Fisher, 2013). Gutter oil contains several carcinogens and can cause severe diarrhea and abdominal pain (Ramzy, 2011). Long-term consumption of food prepared with gutter oil can lead to stomach and liver cancer and developmental disabilities in newborns and children (Global Times, 2011b). This section first describes the gutter oil scandals in mainland China and Taiwan and then makes a comparison between the cases arising in the two different areas.

### *Gutter oil scandal in mainland China*

In mainland China, gutter oil is produced by workshops and small factories and is mainly distributed to street vendors and hole-in-the-wall restaurants that rely on the use of gutter oil to reduce expenses and to gain higher profit margins (Astley, 2012). The gutter oil scandal was first reported in 2000, when it was discovered that a street vendor was selling oil recycled from restaurant garbage disposals (He and Liu, 2011). It did not draw public attention as the authorities asserted that it was an 'isolated incident'. On 17 March 2010, a professor at Wuhan Polytechnic University, He Dongping, claimed that recycled cooking oil had become widely used in Wuhan, and that China consumed 2 to 3 million tons of gutter oil annually (Barboza, 2010), which shocked Chinese consumers and worsened the public's confidence in food safety in China. However, under tremendous pressure from governmental officials, Professor He Dongping held a press conference on 19 March and denied his estimation about the amount of gutter oil consumed by Chinese people every year (Li, 2010). Nonetheless, domestic media continued reporting about the widespread use of illegal cooking oil. Soon after, China's State Food and Drug Administration issued a nationwide emergence notice requiring an investigation of the sources of cooking oil (Barboza, 2010), confirming the presence of gutter oil in the country. On 19 September 2011, a Chinese journalist reporting on the illegal cooking oil scandal was stabbed more than 10 times to death (Goodman, 2011).

The government had launched a number of nationwide campaigns to eradicate the production and sale of gutter oil. In July 2010, for example, the State Council ordered a ban on use of refined restaurant waste in the catering industry (Associated Press, 2010). In a nationwide crackdown carried out in September 2011 the Ministry of Public Security broke up a massive criminal network of illegal cooking oil spanning 14 provinces, demolished 6 factories and sale terminals, seized 100 tons of gutter oil, and detained 32 people allegedly involved in the scandal (BBC News, 2011; Li, 2011; Lu and Wu, 2014). Thirteen

underground workshops across four provinces were smashed, more than 3,200 tonnes of cooking oil made from waste oil were seized, and more than 100 suspects were arrested in March 2012 (Astley, 2012). Another crackdown in April 2013 uncovered a gutter oil production and marketing chain expanding across 13 cities and involving more than 100 people making and selling recycled cooking oil (Fisher, 2013). The Chinese government had also established a series of regulations and laws to strengthen the supervision of gutter oil (Li et al., 2016; Lu and Wu, 2014), such as the act 'Strengthening the Prohibition of Gutter Oil in the Catering Industry' implemented in March 2010, the 'A Pilot Program of Organizing the City's Food Waste Resource Utilization and Innocuous Treatment' released in May 2010, and the 'Strict Punishment for Gutter Oil Crimes' published in January 2012.

Table 3.3 shows the chronology of the gutter oil scandal in mainland China.

Table 3.3 Chronology of gutter oil scandal in mainland China

| Date | Progress |
| --- | --- |
| 17/03/2010 | A professor at Wuhan Polytechnic University, He Dongping, confirmed the widespread use of gutter oil in Wuhan and stated that in China 2 to 3 million tons of gutter oil returned back to dinner tables every year. |
| 19/03/2010 | Professor He Dongping retracted his statement that China consumed 2 to 3 million tons of gutter oil annually. |
| 20/03/2010 | China's State Food and Drug Administration issued a nationwide emergency notice requesting health officials at all levels to investigate the sources of cooking oil. |
| 18/03/2010 | The act 'Strengthening the Prohibition of Gutter Oil in the Catering Industry' came into force. |
| 04/05/2010 | The Chinese government released 'A Pilot Program of Organizing the City's Food Waste Resource Utilization and Innocuous Treatment'. |
| 19/07/2010 | The State Council of China ordered to crack down on 'refined restaurant waste finding its way back to dinner tables through illegal channels'. |
| 20/07/2010 | Professor He Dongping refused to discuss his findings about gutter oil with media. |
| 22/08/2011 | The 'Food Safety Operating Specification in the Catering Industry' was executed. |
| 13/09/2011 | The Ministry of Public Security announced the arrest of 32 suspects making and selling potentially harmful oil in 14 provinces, with 100 tons of toxic oil seized and 6 underground factories smashed. |
| 19/09/2011 | A Chinese journalist, Li Xiang, who covered the dirty business of gutter oil, was stabbed to death on the way home in the city of Luoyang. |
| 21/03/2012 | Chinese authorities confiscated more than 3,200 tonnes of gutter oil, shut down 13 underground workshops across four provinces, and captured more than 100 suspects. |
| 09/01/2012 | The 'Strict Punishment for Gutter Oil Crimes' was published. |
| 04/2013 | Chinese authorities struck down a gutter oil production ring across 13 cities, arrested more than 100 criminal suspects, and seized 3,200 tons of illegal cooking oil. |
| 02/05/2013 | The 'Interpretation of Applicable Law on Handling Cases of Food Safety Crimes' was implemented. |

Sources: Associated Press, 2010; Astley, 2012; Barboza, 2010; BBC News, 2011; Fisher, 2013; Goodman, 2011; Li, 2010; Li, 2011; Li et al., 2016; Lu and Wu, 2014

## Gutter oil scandal in Taiwan

The gutter oil scandal in Taiwan refers to a series of gutter oil incidents.

The first case came to light in 2014, when Chang Guann Co., a well-known cooking oil manufacturer, was found to be producing contaminated cooking oil by mixing normal cooking oil with recycled oil, grease traps, and leather cleaner, and the problematic oil was branded as Chuan Tung Fragrant Lard Oil (Yen, 2014a). The company purchased 243 tonnes of recycled waste oil that were disguised as lard oil from an unlicensed factory and produced a total of 780 tonnes of edible lard oil, which was sold to overseas markets, such as Hong Kong, Brazil, France, mainland China, Macau, New Zealand and so on, and to a great number of food companies, night markets, restaurants, bakeries, schools, and military compounds in 22 cities and counties in Taiwan (Chung and Yan, 2014; Shih, 2014). More than 1,000 food companies had been affected by the scandal including Starbucks, 7-Eleven, Wei Chuan Corp. – one of the biggest food manufacturers in Taiwan, and other large food companies (FlorCruz, 2014; Li, 2014).

The chairman of Chang Guann, Yeh Wen-hsiang, made a public apology on 4 September. On the same day, Taiwan's Food and Drug Administration (FDA) demanded Chang Guann recall the tainted oil by 1 March 2015 (Yen, 2014a). In addition, on 11 September the FDA ordered that 24 oil products made with lard oil supplied by Chang Guann be recalled, as investigation revealed that the company imported 87.72 tonnes of lard oil meant for animal feed from Hong Kong to produce cooking oil (Taipei Times, 2014a). Hong Kong issued a massive recall and banned all 25 lard and lard products imported from Chang Guann on 14 September (Sung, 2014).

Table 3.4 provides the chronology of the first gutter oil scandal in Taiwan.

Table 3.4 Chronology of the first gutter oil scandal in Taiwan

| Date | Progress |
| --- | --- |
| 01/09/2014 | Chang Guann Co., a well-known Taiwanese cooking oil manufacturer, was caught producing tainted cooking oil by mixing lard oil with drainage oil recycled by an unlicensed factory.<br>The company purchased 243 tonnes of gutter oil to produce 780 tonnes of edible lard oil, which was sold to overseas markets and 22 cities and counties in Taiwan. |
| 04/09/2014 | The chairman of Chang Guann, Yeh Wen-hsiang, apologized to the public.<br>Taiwan's Food and Drug Administration (FDA) ordered the company to recall the contaminated oil by 1 March 2015.<br>It was discovered that one of the biggest food manufacturers in Taiwan, Wei Chuan Corp., had used the problematic oil. |
| 05/09/2014 | Premier Jiang Yi-huah ordered that all food and oil products manufactured by 235 food companies using tainted lard oil bought from Chang Guann be removed from |

| | shelves by 7 September 2014. |
|---|---|
| 11/09/2014 | Taiwan's Food and Drug Administration (FDA) demanded that 24 Chang Guann oil products be recalled, because investigators found that the company imported 87.72 tonnes of lard oil intended for animal use from Hong Kong and allegedly used them to make edible lard oil. |
| 13/09/2014 | The chairman of Chang Guann, Yeh Wen-hsiang, was detained on suspicion of fraud. |
| 14/09/2014 | Hong Kong food authorities recalled and banned 25 lard and lard products imported from Chang Guann. |
| 24/07/2015 | The chairman of Chang Guann, Yeh Wen-hsiang, was sentenced to 20 years in jail. |

Sources: Chung and Yan, 2014; Shih, 2014; Sung, 2014; Taipei Times, 2014a; Yen, 2014a

The second case in the string of scandals occurred just a month after revelations of Chang Guann's practice of using gutter oil in its products, when investigators found in October that Taiwanese food giant Ting Hsin International Group was blending animal feed oil with cooking oil and then selling the tainted cooking oil for human consumption (Chung, 2014). The tainted oil was mainly distributed in Taiwan markets (Reuters, 2014), triggering widespread outrage in Taiwan. In response, the Taiwan public called for a boycott of all Ting Hsin's products across the island (Taipei Times, 2014b). Consumers in mainland China and Hong Kong also blacklisted the company. On 11 October, the Food and Drug Administration (FDA) ordered a mass recall of 54 Ting Hsin lard products (Daily Mail, 2014; Hsu, 2014). That same day, senior Ting Hsin executive Wei Ying-chung apologized to the public at a news conference (Chang, 2014). Eight business executives had been arrested in connection with the scandal by 14 October (Chung, 2014). Ting Hsin stated later on 16 October that it would leave Taiwan's oil market and donate NT$3 billion ($100 million) for addressing food safety issues in Taiwan (Yen, 2014b).

Chronology of the second gutter oil scandal in Taiwan is given in Table 3.5.

Table 3.5 Chronology of the second gutter oil scandal in Taiwan

| Date | Progress |
|---|---|
| 09/10/2014 | Prosecutors launched an investigation into a large food company Ting Hsin International Group over mixing animal feed oil with cooking oil. Wei Ying-chung resigned as chairman of three Ting Hsin subsidiaries. |
| 10/10/2014 | Consumer groups in Taiwan urged the public to boycott Ting Hsin's products. |
| 11/10/2014 | The Food and Drug Administration (FDA) ordered a recall of 54 Ting Hsin lard products tainted with animal feed oil the company procured from Vietnam. Wei Ying-chung held a news conference to apologize to the public. |
| 14/10/2014 | Eight Ting Hsin-linked executives had been arrested. |
| 16/10/2014 | Ting Hsin announced that it would leave Taiwan's oil market and donate NT$3 billion ($100 million) to the government to set up a food safety fund. |

| 17/10/2014 | The Changhua District Court granted a request to detain Wei Ying-chung. |
|---|---|
| 27/11/2015 | The Changhua District Court found Wei Ying-chung not guilty. |
| 25/03/2016 | The Taipei District Court found Wei Ying-chung guilty of deceiving consumers and violating food safety laws and gave him a 4-year sentence. |

Sources: Chang, 2014; Chiao, 2015; Chung, 2014; Daily Mail, 2014; Hsu, 2014; Pan, 2016; Taipei Times, 2014b; Yen, 2014b

The third case involved the owner of Beei Hae Edible Co. and Hsieh Ching Corp., Lu Ching-hsieh, who bought animal beef tallow and vegetable oil intended for animal feed from a trading company called Jin Hong and allegedly used the ingredients to manufacture cooking oil (Central News Agency, 2014a). The companies imported a total of 1,427 tons of non-edible oil (Taiwan News, 2014). A portion of the substandard oil was distributed to more than 110 Taiwanese downstream buyers and two Hong Kong-based firms (Chou, 2016). The remaining 582 tons of non-edible oil were mixed with animal feed oil to produce tainted lard oil, which was sold for human consumption. Both the owner and his wife were taken into custody at the end of October 2014. On 3 November, the FDA ordered to remove all oil products made by Beei Hae and Hsieh Ching from shelves (Central News Agency, 2014b).

Table 3.6 demonstrates the chronology of the third gutter oil scandal in Taiwan.

Table 3.6 Chronology of the third gutter oil scandal in Taiwan

| Date | Progress |
|---|---|
| 15/10/2014 | The oil products made by Beei Hae Edible Co. and Hsieh Ching Corp. were found to contain animal feed oil. |
| 18/10/2014 | Prosecutors won the court's approval to detain Lu Ching-hsieh, the owner of Beei Hae Edible Co. and Hsieh Ching Corp. |
| 27/10/2014 | The Tainan District Prosecutors Office (TNDPO) asked health officials to remove products containing oil from Beei Hae and Hsieh-ching. |
| 30/10/2014 | Detention of Lu Ching-hsieh's wife, Lu Huang Li-hua, who was the nominal head of the two companies, was approved by the court. |
| 03/11/2014 | The Food and Drug Administration (FDA) ordered to take all oil products manufactured by the two companies off shelves in Taiwan. |
| 29/06/2016 | The Taiwan District Court sentenced Lu Ching-hsieh to four years and six months in prison, while his wife Lu Huang Li-hua was sentenced to four years. Their companies were fined a total of NT$9 million. |

Sources: Central News Agency, 2014a; Central News Agency, 2014b; Chou, 2016; Taiwan News, 2014

This section makes no attempt to draw conclusions from the depictions of the three Taiwan gutter oil scandals as the main purpose is to compare the mainland China gutter oil scandal with the Taiwan scandals.

## *Comparison of gutter oil scandals*

There are some similarities as well as differences between the gutter oil scandal in mainland China and those in Taiwan. What they had in common were:

1) they all entailed strong public risk responses,

2) they all involved sustained and intense engagements of the government in tackling the problem,

3) they all involved a chain of suppliers and distributors contributing to the widespread use of gutter oil.

Their differences were mainly manifest in the following four aspects:

1) the mainland China scandal involved many low-end restaurants, underground workshops, and small factories, which were not serious contributors to the risk communication process, while Taiwan scandals all involved well-established companies, which played significant roles in shaping public perceptions of risk,

2) the Taiwan gutter oil incidents all involved well-defined oil products, while illegal cooking oil in mainland China had no brand name or was falsely labelled,

3) societal risk responses in Taiwan were more detectable than in mainland China as both the products and producers were clearly defined,

4) in mainland China gutter oil and related products were not recalled by producers but seized by the authorities, while in Taiwan producers implemented recalls of tainted oil and oil products.

These differences largely reflect how the nature of risk events can vary with the social context in which risk events are situated. They also indicate how important social interactions and clear organizational activities are for exploring the mechanism of social risk amplification in the context of product contamination crises.

Figure 3.3 shows the Google Trends plot of gutter oil scandals. This illustrates the volume of search using the term 'gutter oil scandal'. Unlike the Sanlu case and the Nonfu Spring water case, there is a strong late peak after a fluctuating low level of concern, and a relatively high level of concern after this point. The strong residual concern is a reflection of large ripple effects produced by the crisis. The significance of the additional symbol over point H on the plot provided by Google is unknown.
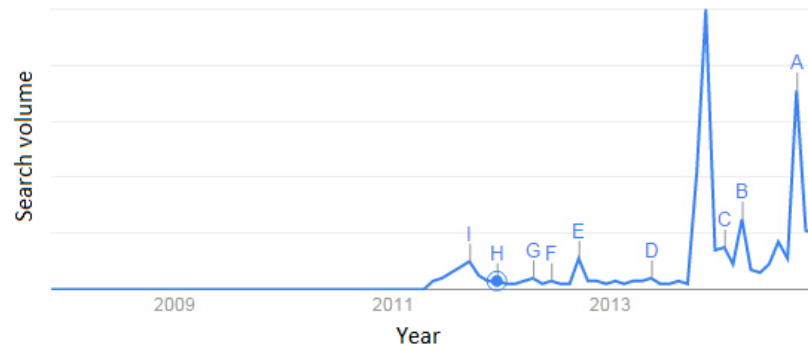
A: Taiwan oil supplier fined $1.6m over 'gutter oil'

B: Singapore National Environment Agency (NEA) looking into gutter oil extraction incident

C: Shandong court sentences man to death for making and selling 'gutter oil'

D: Gutter oil to be used as auto fuel

E: Chopped liver, gutter oil and China's private borrowers

F: Gutter oil to be exported for jet fuel

G: Beijing may use cameras to monitor gutter oil

H: 52 held in China over 'gutter oil'

I: Police in China seize 100 tons of 'gutter oil'

Source: Google Trends (2014). *Search term: gutter oil scandal*. Available at:

https://trends.google.com/trends/explore?q=gutter%20oil%20scandal [Accessed 6 December 2014].

Figure 3.3 Google Trends of gutter oil scandal

# 3.4 Summary

The aspects that the three cases had in common were:

   1) they all involved a well-defined product that could lead to serious health problems,

   2) they all received widespread publicity during the times of crisis, and media played a crucial role in affecting public perceptions of associated risks,

   3) they all had the government as an important amplification station,

   4) they all caused a loss of public trust in the government and in the relevant industries.

The commonalities seem to make each of the cases an appropriate candidate for the context in which the mechanism of social risk amplification can be investigated.

   However, the differences between them show clearly which case is the best choice. *First*, no product recalls were made during Nongfu Spring water event, while there were recalls of products made from recycled oil in the gutter oil scandal and recalls of tainted baby milk in the Sanlu case. As product recall process is considered as a significant amplifier of risk in product related crises and a critical component of the model, Nongfu Spring water event is excluded.

*Second*, in the mainland China gutter oil case many small organizations served as risk agents, such as small factories and industrial oil refiners, whereas the milk scandal involved one big company, i.e. the Sanlu Group, who made decisions about whether, when, and how to conduct the recall. It may be difficult to determine how the public interact with organizational decision making when a number of organizations are responsible for managing the risk. Involving a single company can provide a good reference for the way in which organizational communication contributes to risk estimates of the public in a recall event.

*Third*, both the Sanlu case and the Taiwan gutter oil scandals involved one main well-known producer, but the former saw much stronger risk responses than the latter. Because response mechanism is the core of SARF (Kasperson et al., 1988), it is natural to choose the case with more intense public reactions.

As a result, the Sanlu milk contamination event is eventually chosen for the model. It is the case in which there was a clear recall event as well as a strong social risk response, and the one that has been most reported in the literature. The main features that are going to be relevant for the modelling include a single producer issuing a product recall, recreancy, and media communication. There are some reasons why 'government' is not considered as an actor in the model described in Chapter 5, however. First, it is unclear how the government and producer interact, especially given the relative secretiveness of government operations in China. Second, it is much more complex to capture in a model how people judge the competence of the government compared with that of the producer – this is because the government plays multiple or unclear roles, such as protecting the public, supporting an industry, supporting exports, and so on. Third, in China it is much harder for people to comment on the conduct of government compared with commenting on the conduct of companies. People are often afraid to criticise government, specifically.

# 4 RESEARCH DESIGN

This chapter is composed of two parts. The first part presents the research questions and objectives of this study. The second part centres on process and methods of modelling. Themes in this section include 1) choice of agent-based modelling that describes the nature and application of agent-based modelling as well as justification and problems in the use of agent-based modelling, 2) overall process of modelling undertaken in this study, and 3) validation procedures that are necessary and feasible for the study.

Figure 4.1 presents the flow of this study that goes from research questions to modelling and to model validation. The lines with arrows indicate the formalisation process and model validation process, and those without arrows show how research questions are answered and how validation is achieved.

Figure 4.1 Flow of study

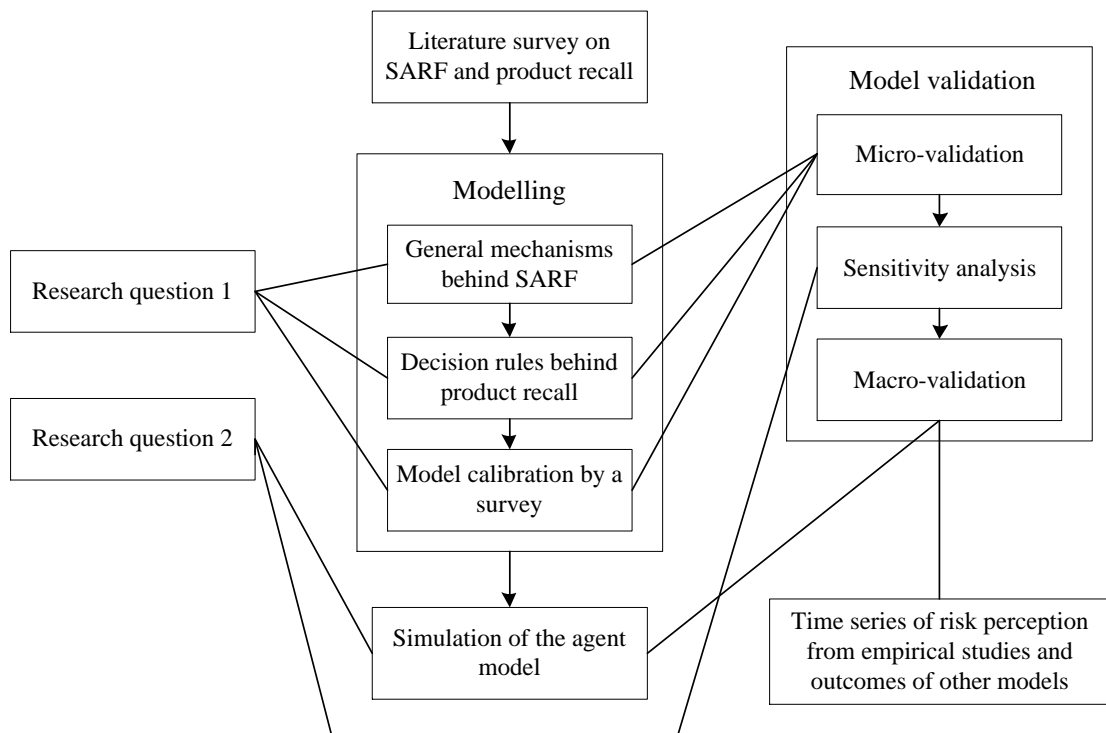## 4.1 Research questions and objectives

Drawing on SARF, this study attempts to make a commitment to the mechanism explaining how social actors interact with each other to shape collective risk response during a product recall crisis. It particularly concentrates on the interaction between an organization's decision making and the public response during such a crisis. The primary concern is the public's

perception of the risks that it bears, and how this perception develops in a context of this kind. Given these considerations, the main research questions are:

1) how can we formalise social amplification of risk in the context of a product recall event?

2) what can we learn from the formalisation?

There are some subsidiary research questions:

1) how can the process of forming risk responses be modelled?

2) what kind of empirical data does the modelling need?

The main research objectives are:

1) to build an agent-based modelling of social risk amplification in the context of a product contamination crisis,

2) to carry out empirical work to help calibrate the model,

3) to assess the outcomes of simulating the model, and to assess what contributions the work makes to the literature on social risk amplification.

## 4.2 Process and methods of modelling

### 4.2.1 Choice of agent-based modelling

*Nature and application of agent-based modelling*

Agent-based modelling (ABM) is a modelling and simulation technique that allows examination of how collective patterns emerge as a result of interactions among multiple agents within an environment (Farmer and Foley, 2009; Macal and North, 2014). A typical agent-based model consists of three elements – agents, agent relationships, and agents' environment (Macal and North, 2014). In ABM an agent is a simplified, abstract version of actors in a system, which could be individuals, organizations, and even nation states. Agents are autonomous and make independent decisions in response to stimuli that arise in their environments. They are identifiable and discrete in the sense that they possess a set of attributes and rules that govern their behaviours, decision-making capability, and interactions with other agents (Macal and North, 2009).

Agents in agent-based models typically exhibit some form of bounded rationality (Epstein, 1999; Kimbrough and Murphy, 2013). Agents do not act with complete information or infinite computational capacities. Instead, they make use of their decision rules under limited time, knowledge, and computing power (Gigerenzer and Goldstein, 1996). And the heuristics agents adopt to interact locally are boundedly rational as they can lead to biased choices

(Conlisk, 1996). Agent relationships concern the specific topology depicting social interactions among agents – how agents are connected to, and interact with, other agents.

ABM has gained popularity in many fields of study (Heath et al., 2009) and has been commonly used to theorize about system behaviour and to capture the dynamic process within a system. It best fits modelling and simulation of systems involving multiple interacting autonomous entities. In essence, ABM is an instrument to build a bridge between agent behaviours and interactions at the micro-level and global consequences emerging through interactions at the macro-level (Smith and Conrey, 2007). Macy and Willer (2002) pointed out that 'ABMs provide theoretical leverage where the global patterns of interest are more than the aggregation of individual attributes'.

Miller (2015) elaborated on the nature and purpose of agent-based modelling from a critical realist perspective. Critical realism, on the one hand, holds a realist ontology that a phenomenon can exist independently of people's knowledge of it (Fleetwood, 2005). On the other hand, it recognizes a fallibilist epistemology that human knowledge is socially produced (Miller and Tsang, 2011) and therefore not a complete or objective understanding of a phenomenon such as a contaminated product. In particular, critical realists explain a phenomenon in terms of its mechanisms. Agent-based modelling corresponds well with the critical realist principles in the sense that it is a phenomenon-centred approach (Miller, 2015) and especially helpful to address 'backward' problems – exploring mechanisms lying behind a phenomenon of interest (Macy and Willer, 2002; Smith and Conrey, 2007). A recent example of how such an exploration can take place is provided by Liu and Brooks (2016) who propose the implementation of several competing models of herding behaviour in financial markets. Modelling SARF is exactly a problem of this kind as it is a process of identifying the mechanism of how agent behaviours and interactions give rise to the phenomenon of social risk amplification rather than a process of exploring the implications of a mechanism that is already known before doing the modelling. Furthermore, it is argued that agent-based modelling of organizational phenomena primarily requires a transformation from correlations among variables to process conceptualisations (Miller, 2015). This is compatible with the conclusions drawn from past empirical work on SARF (Chapter 2) that statistical associations among variables can show little evidence for real mechanisms of risk amplification, and that identifying the mechanisms demands an explanation of the empirical phenomenon as emerging from interactions of underlying processes.

Critical realists also claim that simplification is necessary for the modelling of the phenomenon in order to maintain core assumptions and to make the underlying mechanisms more transparent. This also supports agent-based modellers' practices. Smith and Conrey (2007) argued that 'an ABM is a representation of a theory about social behaviour, not a representation of some slice of complicated social reality'. Adding theoretical components or

processes that are not essential or conceptually critical can not only obscure fundamental aspects of the phenomenon but also undermine the explanatory power of the model to theorize about the phenomenon under investigation (Weirich, 2011). And it is simply unrealistic to cover all features of the target phenomenon in an agent model. What's more, simple models can generate complex consequences as a result of agent interactions (Axelrod, 1997; Gilbert and Terna, 2000). As the goal of modelling SARF in the context of a product recall crisis is to understand the fundamental process that gives rise to social amplification of risk, it is not important to represent all the details of such a crisis but to capture effects that are crucial for the phenomenon.

A critical realist perspective on the application of agent-based modelling is that ABM is well-suited for interactively complex epistemologically-emergent phenomena in which emergent outcomes cannot be obtained by adding up the behaviours of all components (Miller, 2015). In other words, ABM can be most effectively applied to moderately complex contexts that are not too simple or extremely complex. They are the kind of contexts that are, as Miller (2015) has suggested, 'beyond the grasp of unaided human cognition but amenable to parsimonious specification'. The SARF context seems to satisfy this boundary as social risk amplification involves relatively complicated interactions and processes that one is unable to evaluate accurately through intuition but can be analysed through an appropriate model and simulation of such a model.

It appears that there is close relevance of critical realism to agent-based modelling of social risk amplification in terms of mechanism, simplification of assumptions, and complexity of context. Renn et al. (1992) argued against a purely subjectivist view of risk amplification, and critical realism seems to fit their argument quite well. To the extent that critical realism also supports the use of agent modelling, agent modelling looks like an appropriate tool to explore SARF.

## *Justification and problems in using agent-based modelling*

The justifications for using agent-based modelling specifically in this study are as follows.

First, the social amplification of risk framework (Kasperson et al., 1988) emphasizes that signals about risks or risk events are conveyed and processed by a variety of autonomous actors seen as 'amplification stations' that are self-directed in making risk decisions in the communication process. Messages spread between actors through an environment in which they are located and by which they are affected. The possibility of using system dynamics model is also considered. System dynamics models describe dynamic behaviour of a system in terms of associations between variables rather than actors involved in the system. This is

obviously far from modelling SARF, which requires a focus on actors responsible for the underlying processes of risk amplification. The possibility is therefore ruled out.

Second, empirical studies on SARF (for example, Binder et al., 2011; Smith et al., 2013) and risk perception (for example, Muter et al., 2013; Scherer and Cho, 2003), as well as empirical work in such domains as medicine (for example, Bernardi, 2002; Smith, 2006) and psychology (for example Knoll et al., 2015), have highlighted the importance of social interactions in shaping individuals' perceptions of risk. Social interactions exert contagion effects on risk perceptions in ways that facilitate exchange of risk information and engagement in risk related behaviour. Hence, actors' risk responses are interdependent – each actor's risk perception depends on not only its own estimates of risk but also the responses of other actors. Thus, social networks serve as important channels through which actions among actors take place. On the one hand, social networks shape actor interactions as they provide pathways of creating social ties among actors. On the other hand, they are shaped by actor actions as the formation of social networks relates to the rules of how actors interact with each other.

Third, as Busby et al. (2016) have suggested, nonlinearities are critical to the emergence of risk amplification. Some modelling of social risk amplification (Bleda and Shackley, 2012; Burns and Slovic, 2007; Busby and Onggo, 2013; Busby et al., 2016; Onggo et al., 2014) has shown how complex are the feedback loops between risk communication, risk perceptions, and behavioural responses and how the feedback effects can contribute to heightened risk in excess of what one might expect. Agent modelling naturally produces such nonlinearities as a result of the network-based interactions of agents over time.

Fourth, in a risk event actors are heterogeneous in attributes and risk responses. Both theoretical (Slovic et al., 1982) and empirical (for example, Chauvin et al., 2007; Marris et al., 1997; Sjöberg, 2000) work has identified the existence of individual heterogeneity in risk issues. Agent models, precisely because the basic unit of the model is the agent, allow a natural and logical representation of this heterogeneity. As Rahmandad and Sterman (2008) pointed out, 'AB models can readily include heterogeneity in individual attributes and in the network structure of their interactions'.

There are also problems in the use of agent-based modelling. As mentioned earlier, it is impossible to incorporate every detail regarding the phenomenon of social risk amplification in an agent model. Epstein (1999) noted that 'The agent-based approach forces on us the interpretation of society as a computational device, and this immediately raises foundational specters of computational intractability and undecidability'. As a result, the explanation of risk amplification that the model offers is partial to the extent that the model inevitably simplifies assumptions by eliminating nonessential and inaccessible aspects. Weirich (2011) said that a simulation model is 'a component of an imaginary complete world'. It imitates how

a natural system produces a phenomenon of interest, but it does not necessarily aim to provide an accurate representation of the phenomenon. The agent-based computational modelling, as Busby et al. (2016) argued, 'represents a reasonable direction for representing amplification more precisely, and working out the consequences of such a representation'.

## 4.2.2 Overall process of modelling

The process of modelling risk amplification in this thesis is essentially a process of increasing contextualisation of risk amplification. It goes from a model based on general ideas of SARF to a model also incorporating decision rules derived from literature on the specific type of crisis (in this case, product recall) to a model also calibrated from a consumer survey. To be more specific, the modelling starts by drawing upon theoretical and empirical work on SARF to figure out general mechanisms underlying social risk amplification. The purpose of this step is to build a model in which no assumptions are made about a context. In the next step the model introduces variables that are contextual to a specific domain of organizational crisis (i.e. product recall). It does this by drawing on empirical associations found in such a context, and translating these into agent rules. The last step involves calibration of the agent model by using a survey to find empirical values for the priorities found in the agent rules – in this case priorities that evaluate the relative importance of different sources of risk information. This makes the model specific to a particular population experiencing a particular organizational crisis.

The details of each of these three main steps are contained in Chapter 5 and Chapter 6. The important point is that SARF, as a general framework, cannot be a sufficient basis for any model for some actual situation. It has to be augmented by knowledge of the type of situation in question, and then by knowledge of how the population in question responds in that type of situation.

## 4.2.3 Validation procedures

There are two stages of validation for agent-based models: micro-validation and macro-validation (Midgley et al., 2007; Moss and Edmonds, 2005). The first stage refers to the micro-validation of behaviour of individual agents, and the second stage the macro-validation of aggregate behaviour resulting from agent interactions in the model. The ABM literature has shown that micro-validation is commonly conducted (for example, Bulleit and Drewek, 2011; Ghorbani et al., 2015; Leykum et al., 2012), and that approaches used for such validation is relatively extensive, such as model building (for example, Dubois et al., 2013; Fonseca et al., 2015) and model parameterization (for example, Arciero et al., 2009; Zechman, 2011).

Validating agent-based models at the macro-level has been a long-standing obstacle for researchers mainly due to the lack of adequate data. Nonetheless, methods including sensitivity analysis (for example, Fonoberova et al., 2013; Kimbrough and Murphy, 2013; Nagarajan et al., 2012) and comparison of model output with plausible data (for example, Christensen and Sasaki, 2008; Liu and Wu, 2016) have been widely used in ABM-based studies to obtain a certain level of assurance in the model.

In regard to validation of the agent model in this thesis, the planned procedure is micro-validating the model through the contextualisation process mentioned above, sensitivity analysis, and macro-validating the model by comparison with literature showing time series over crises. The procedures and outcomes will be described in detail in Chapter 7. But the basic logic is as follows:

1) The micro-validation involves associating each aspect of the model, particularly the agent decision rules, with claims in the literature, mostly having at least some empirical basis.

2) The sensitivity analysis involves identifying how the primary outcome – the degree of difference between public risk perception and the expert risk assessment – varies as the main model parameters vary, and assessing the significance of this.

3) The macro-validation involves comparing traces of the primary outcome with some measure or proxy for the same outcome in empirical studies of past crises, in an attempt to show at least that the model is consistent with behaviour in those crises.

As will be described, the macro-validation process is very limited in what it achieved, because of the problems of getting longitudinal measures of public risk responses during a crisis.

# 5 AGENT-BASED MODELLING AND SIMULATION

This chapter demonstrates the development of the agent-based models and the results of simulating the models. It is composed of two sections in accordance with the kind of model developed, as shown in Figure 5.1. The first section describes the process of building an agent model with a perfectly mixed population and presents results of simulating the model. The second section deals with an agent model with agents interacting in a small-world network and simulation results of such a model. The simulation results for each of the two cases are given over a series of stages as the model is developed with increasing complexity.
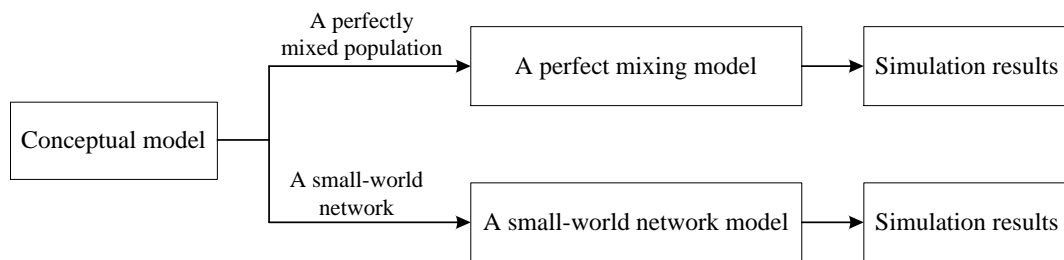
Figure 5.1 Structure of Chapter 5 Agent-based Modelling and Simulation

## 5.1 Conceptual model underlying both agent models

In accordance with the incremental development principle of agent-based modelling, this model is built up in simple steps. As shown in the conceptual model in Figure 5.2, an individual agent's risk perceptions are shaped by two essential processes: 1) the discovery of a danger and the processing of information indicating the scale of this danger; and 2) the formation of a perception of recreancy or misconduct. The discovery process draws information from that agent's prior beliefs, from the beliefs of others that it interacts with, from any direct experience (for example illness following ingestion of a contaminated food product), and from a producer's recall. The recreancy process involves assessing the timing and voluntariness of the recall process. The justification for these specific variables is given, in detail, below in Section 5.2. In any specific, real case there may be many more considerations that influence the recreancy process, but at a minimum, for a recall crisis, it should involve timing and voluntariness of the product recall. These influences then combine with communication from the media of any kind relevant to an agent.
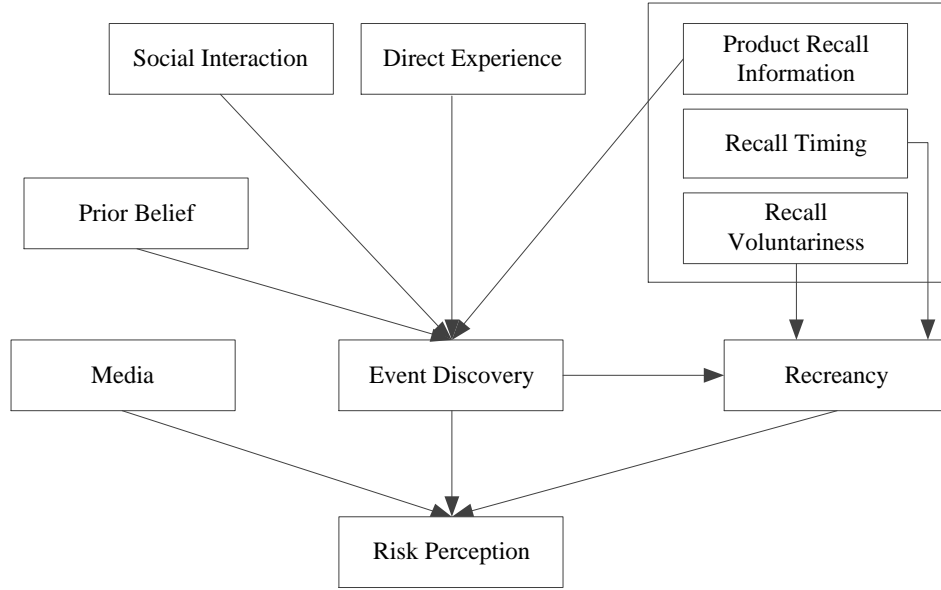
Figure 5.2 Conceptual model of a social agent developing a risk perception to a product recall

This conceptual model does not specify the nature of the population and how interactions within this population are selected.

## 5.2 A perfect mixing model

### 5.2.1 Model development

### 5.2.1.1 Basic model

According to SARF (Kasperson et al., 1988), communication is at the heart of social amplification of risk. Communicating with others is one common channel through which individuals are exposed to information about risks or risk events. Interpersonal contacts provide a pathway for individuals to create, exchange, and reframe risk information. Moreover, interpersonal communication has received relatively little emphasis in research on social risk amplification, and its effect on public risk perception remains somewhat in question.

In the basic model there are $N$ agents who interact with randomly chosen peers in a perfectly mixed population. Perfect mixing means that any agent can interact with any other agent. Individuals' risk beliefs are heterogeneous. In the absence of any information about an agent population's initial beliefs, at the start each agent $i$ is endowed with a risk belief $b_i(t=0) \in [0, I)$, which is sampled from a uniform distribution. This means that there is no

bias towards any particular initial belief. What is meant by a 'risk belief' $b_i(t)$ is a subjective probability that indicates how likely the agent $i$ thinks the outcome in question is. The outcome in question, for the purpose of the model in the product contamination context, is a harmful contamination. In other words, $b_i(t)$ represents an agent $i$'s belief of the proportion of products being contaminated, or of the probability that it will experience the contamination if it consumes the product (which is the same). Agents' risk beliefs have no effect on their consumption behaviour. This may or may not be a realistic assumption, depending on how easy it is for consumers to substitute for this product, and how serious the health consequences are. In the calibrating survey, the example is of liquid milk products, and for some people this might be much more substitutable than for others depending on their circumstances.

In every period of the model, an agent $i$ is randomly selected for activation, with an equal probability $1/N$ of each agent being selected. Activating only one agent in every period makes it possible to look at every change in the model and to verify the model is working as expected. Activating all agents still creates the need to randomise the order in which they are activated and ends up with a sequential activation. Also, it is perhaps unrealistic that every agent will be active with the same frequency anyway, and activating one agent per tick, with replacement (i.e. an agent that has been activated at the previous tick has an equal probability of activation at the next tick) means there is a random distribution of activation frequencies over the population. Agents mix with each other in some random way, such that an activated agent $i$ interacts with $K$ neighbours with risk belief $b_{nj}(t)(j = 1, 2, \cdots, K)$ that are picked at random. An agent $i$ updates its risk belief based on its prior belief and mean risk belief of neighbours, that is:

$$b_i(t) = \frac{1}{2}\left( b_i(t-1) + \frac{1}{K}\sum_{nj=1}^{K} b_{nj}(t) \right) \tag{5.1}$$

In the absence of further information, the contributions to the new risk perception are equally weighted, but this weighting, as is described in Chapter 6, will eventually be calibrated from a consumer survey.

## 5.2.1.2 Adding contamination

This stage introduces an objective product contamination event that lasts for quite some time. A contamination level $C(t)$ expresses the probability that any activated individual will directly experience a harm caused by the product. In the context of the model, this probability is equal to the actual proportion of contaminated products. Therefore, the contamination level

expresses an objective probability that can be compared with the subjective probability estimates represented by the agents' risk beliefs. Contamination level is set as a constant in the model, and its value is very small prior to and after the contamination incident and high during the incident:

$$C(t) = \begin{cases} C_{low}(t) & t < T_{start} \ \ or \ \ t > T_{end} \\ C_{high}(t) & T_{start} \le t \le T_{end} \end{cases} \tag{5.2}$$

where $C_{low}(t)$ represents the contamination level before and after crisis and $C_{high}(t)$ the contamination level during crisis, and $T_{start}$ signifies the time when the crisis starts and $T_{end}$ the time when the crisis ends. It is assumed that when the contamination level drops at the end of the contamination period, the probability of a consumer experiencing a contaminated product drops at the same time. This assumes that consumers consume the product and know if it is contaminated as soon as they buy a product: they do not store it before consumption.

Direct experience can contribute to formation of risk responses (Masuda and Garvin, 2006; Petts and Niemeyer, 2004), because it helps enhance individuals' knowledge about a risk event and leads to learned perceptions of risk. Direct experience with risk events can serve as either a risk amplifier or attenuator. On the one hand, it can reinforce the memorability and imaginability of hazardous events, thereby exaggerating perceived risks. On the other hand, it also enables individuals to recall the nature and controllability of the events, encouraging active actions for avoiding related risks. Rogers (1997) pointed out that perceived risk is likely to adjust dynamically to personal experience of risky events. Consequently, in the model direct experience is treated as an important information source.

In the model after a product contamination incident is revealed, individuals either have direct experience with the specific risk or they do not. They are assumed to consume the product once, when active, and this product will be contaminated with a probability $C(t)$. Direct experience, $e_i(t) \in \{0,1\}$, is binary and therefore has a strong effect on risk perception. Agents do not have memory of having had a contamination experience, so $e_i(t)$ does not represent an agent's past experience but the current, direct experience of consuming the contaminated product. Its prior belief retains the effect of an earlier experience, but it does not remember it directly. For the sake of simplicity, randomise agents' experience $e_i(t)$ using a random number $m_i(t) \in [0,1)$, such that $e_i(t) = 1$ if $m_i(t) < C(t)$ but 0 otherwise. Direct experience is now added to the decision rule:

$$b_i(t) = \frac{1}{3}\left( b_i(t-1) + \frac{1}{K}\sum_{nj=1}^{K} b_{nj}(t) + e_i(t) \right) \tag{5.3}$$

## 5.2.1.3 Adding product recall

To date, the SARF literature has provided little evidence on the ways in which risks can be amplified by the very organizations having responsibilities to handle them. The main exception to this is the work of Freudenburg (2003) who has suggested that the perception of organizational functioning can have a great influence on perceptions of real risks. He used the term 'recreancy' to denote the failure of an organization to meet its obligations. In particular, product recall is one of the most common responses from the company involved (for example, Choi and Chung, 2013; De Matos and Rossi, 2007; Souiden and Pons, 2009) and of the most important sources of negative publicity that can significantly raise public concern (for example, Desai and Patel, 2014; Korkofingas and Ang, 2011; Magno, 2012; Souiden and Pons, 2009). However, there has been little work on how product recalls contribute to the process of risk amplification in risk events. How risk is socially amplified and how public risk perception evolves over time in a recall event is still a crucial topic to be addressed.

This stage of model development introduces product recall to look at how individuals perceive the risk of products in question and how they make a decision about actions to take upon hearing news of a product recall. The product recall literature was reviewed to extract decision rules relating to consumer responses to recalls. As demonstrated by Chattoe-Brown (2014), agent-based modelling provides a way of integrating different kinds of research data, and for this study the aim was to draw on various pieces of empirical research in the recall literature. The recall literature survey is not presented in this thesis, because this study does not contribute to the recall literature but is used in contextualising risk amplification down to a specific domain of crisis, in this case product recall. The extraction of decision rules for the agent model was carried out as follows:

1) From each empirical study of product recall, identify the causes (independent variables) and effects (dependent variables) underlying agent (e.g. consumer, organization, and media) behaviour.

2) Translate these aggregate, statistical relationships into condition-action decision rules, mapping causes into condition codes and effects into action codes. The complete result of this exercise is tabulated in detail in Appendix A.

3) For condition codes, use a threshold to represent the magnitude of numerical variables (e.g. if the condition is 'consumers perceive high risk for the defective product', then the condition code is 'Perceived Risk > $R_H$'), and use "True" or "False" to denote the value of Boolean variables (e.g. if the condition is 'the company issues a product recall', then the condition code is 'Recall = True').

4) For action codes, a multiplication function is adopted to combine the effects of multiple independent variables on one dependent variable. For example, if the description is 'If

consumers are highly involved with recalled products and perceive the CEO's apology speech as truly sincere, then an apology has more positive effects on consumer attitudes', then the condition codes will be written as 'Involvement > $I_H$ and Sincerity (Apology) > $S_H$ ', and the action code will be expressed as 'Attitude$_t$ = Attitude$_{t-1}$ + $c$ × Involvement × Sincerity (Apology)' with some constant $c$.

5) Classify decision rules in terms of dependent variables, i.e. effects, to facilitate further selection. The decision rules can be classified into four categories generally: organizational reputation, risk perception, brand attitude, and purchase intention.

6) Specify the variables that are significant to consumers' perceptions of risk in the particular context being modelled. For example, product involvement significantly affects consumers' judgment of risk associated with a questionable product (Choi and Lin, 2009a; De Matos and Rossi, 2007), but it is not considered in the milk contamination context model. This is because product involvement is measured by many indicators with respect to consumers' inherent needs, values, and interests (Zaichkowsky, 1985), and incorporating this variable in the model will add excessive complexity to the model.

Based on the agent rules extracted from the recall literature, recall information, recall timing, and recall voluntariness are chosen as critical elements influencing consumer reaction to recall events. This justifies part of the conceptual model presented in Figure 5.2. Thus there are two main aspects to the effect of a product recall on public perceptions: 1) it provides information that the product is defective, which combines with the three sources of information already described to determine public risk beliefs; 2) it increases or decreases the public's trust in the company – depending on its timing, and whether it is voluntary. This is shown in the conceptual model in Figure 5.2.

The second effect, on recreancy, will be dealt with in the next section. For the first, information effect, the model assumes a single producer agent. The producer issues a recall message during the time between contamination release and contamination termination, but does not withdraw the product, and therefore consumers can continue to experience a contamination event. Note that the contamination level $C_{high}(t)$ stays constant when a recall is in force, which means that the recall does not affect the proportion of products that are contaminated. This represents a situation in which the producer simply makes an announcement of recall and contaminated products are still on sale and a situation in which producer behaviour has no impact on the likelihood of consumers experiencing contamination. It obviously differs from a more realistic situation in which a recall is associated with product withdrawal that can affect contamination level over time. The delay between recall announcement and recall action is assumed to be zero for the sake of convenience. The recall announcement $a(t)$ is either 0 (no announcement) or 1 (announcement). The recall is issued

with a probability equal to the contamination risk $C(t)$ at any given time. This means the recall timing is random but the most likely delay is 1 tick only and the delay is distributed as an exponential distribution. There is likely to be some, small delay between the sudden contamination increase and the recall. After a recall announcement has been made, the recall, $r(t) \in \{0, 1\}$, stays in force until the contamination level falls to its original, very low level, that is, $r(t) = 0$ until $a(t) = 1$, then $r(t) = 1$ until $t = T_{end}$, and then $r(t) = 0$. The public's risk belief decision rule now also incorporates recall information (simply a binary value):

$$b_i(t) = \frac{1}{4}\left( b_i(t-1) + \frac{1}{K}\sum_{nj=1}^{K} b_{nj}(t) + e_i(t) + r(t) \right) \qquad (5.4)$$

These four factors including an agent's prior belief, neighbours' perception, direct experience, and product recall information is described in summary as the 'discovery' component of the conceptual model (see Figure 5.2).

## 5.2.1.4 Adding recreancy

The second effect of product recall relates to trust and recreancy. Recreancy was defined by Freudenburg (1993) as the belief that the producer has betrayed the public trust and fails to fulfil its obligations. Freudenburg (2003) showed that recreancy was one of the most important influences on social risk amplification.

As indicated above, there are two aspects drawn from the recall literature that appear relevant to recreancy. An early, voluntary product recall indicates that a firm is acting in a socially responsible way, and a late, forced recall indicates the opposite. Hence, recreancy is influenced by the timing of the recall – the time between the first signal of product defect and the recall of the product from the market. It is also influenced by its voluntariness: if the producer is forced by the authorities to recall the products, recreancy will be higher than if not. So only if the recall is broadcast before the consumer believes the risk has increased and is voluntary, perceived recreancy will be low and this will reduce risk perceptions. Specifically, immediate action without delay, or voluntary product recalls, is seen by consumers as responsible business behaviour, while the delay of the recall, or involuntary product recalls, can be perceived by consumers as due to the indifference of the company (Magno, 2012). As a consequence, consumers' subsequent risk perceptions will be a function of their recreancy belief: if recreancy is high, risk perception will be higher, and vice versa.

Each agent expresses a recreancy belief $R_i(t = 0) \in [0, I)$ from the start. With no recall in force, the recreancy perceived by an agent will be increased by some increment $D$, if and when its risk perception $b_i(t-1)$ equals or increases above some threshold $B$, but stay

unchanged otherwise. In this condition the agent has determined there is a risk and yet heard no recall. And each agent only increases its recreancy belief once, because recreancy primarily concerns finding out an organization has failed to fulfil its obligations and ordinarily this only occurs once, even if the emotion consequences recur many times (Freudenburg, 1993). The updating rule for recreancy $R_i(t)$ is thus:

$$R_i(t) = \begin{cases} R_i(t-1) & b_i(t-1) < B, \ t < T_{a(t)=1} \ or \ t > T_{end} \\ R_i(t-1) + D & b_i(t-1) \geq B, \ t < T_{a(t)=1} \ or \ t > T_{end} \end{cases} \tag{5.5}$$

where $T_{a(t)=1}$ denotes the time when a recall announcement is made and $T_{end}$ the time when the crisis ends. This can only happen once for each consumer, so $D$ can only be added once.

When a recall is in force, consumers update their recreancy beliefs only if they get activated in this period. In this process recreancy also alters only once. To make sure that recreancy is altered only once, introduce another variable $h_i(t)$ to denote whether an agent has already heard the recall:

$$h_i(t) = \begin{cases} 0 & t < T_{a(t)=1} \ or \ t > T_{end} \\ 1 & T_{a(t)=1} \leq t \leq T_{end} \end{cases} \tag{5.6}$$

Also, there is a binary variable, $v(t) \in \{0,1\}$, which denotes that the recall is voluntary ($v(t)=1$) or involuntary ($v(t)=0$). The associated decision rule is that if a recall is forced ($v(t)=0$) and an agent hears the recall ($h_i(t)=1$), then recreancy $R_i(t)$ is increased by some increment $E$, and that if a recall is made voluntarily ($v(t)=1$) and an agent hears the recall ($h_i(t)=1$), then recreancy $R_i(t)$ is reduced by the same amount:

$$R_i(t) = \begin{cases} 1 & v(t)=0 \ \& \ h_i(t)=1 \ \& \ R_i(t-1)+E > 1 \\ R_i(t-1)+E & v(t)=0 \ \& \ h_i(t)=1 \ \& \ 0 \leq R_i(t-1)+E \leq 1 \\ 0 & v(t)=1 \ \& \ h_i(t)=1 \ \& \ R_i(t-1) < E \\ R_i(t-1)-E & v(t)=1 \ \& \ h_i(t)=1 \ \& \ R_i(t-1) \geq E \end{cases} \tag{5.7}$$

where $T_{a(t)=1} \leq t \leq T_{end}$. As $v(t)$ is fixed for any instance of the model, this is a model parameter.

Combine the risk perception emerging from the discovery process outlined in equation (5.4) with that shaped by recreancy in an extended decision rule:

$$b_i(t) = \lambda \left( \frac{1}{4} \left( b_i(t-1) + \frac{1}{K} \sum_{nj=1}^{K} b_{nj}(t) + e_i(t) + r(t) \right) \right) + \delta R_i(t) \tag{5.8}$$

where $\lambda$ and $\delta$ are the weight given to 'event discovery' and 'recreancy', $0 < \lambda < 1$, $0 < \delta < 1$, and $\lambda + \delta = 1$.

## 5.2.1.5 Adding broadcast media

As also shown in the conceptual model, agents update their beliefs in the light of interaction with news media. SARF (Kasperson et al., 1988) has recognized the importance of media to how society processes risk messages. As one of the most important communication channels the news media make decisions on what information to convey, what audience to cover, what story elements to emphasize, and how to articulate a risk issue. Empirical findings have shown that the variations in public risk perception generally accord with the patterns of media coverage including communication mechanism (Lewis and Tyshenko, 2009), nature of risk information (Frewer et al., 2002; Liu et al., 1998), and amount of press coverage (Loewenstein and Mather, 1990; Renn et al., 1992; Yeo et al., 2014). In addition, the media is likely to manipulate messages selectively to raise public concern over a risk issue, directing public attention toward rare or dramatic risk problems and away from those that are more commonplace but more serious (Boyd and Jardine, 2011; Burgess, 2012; Hill, 2001; Kasperson and Kasperson, 1996; Lofstedt, 2008).

Some studies (Bakir, 2005; Boyd and Jardine, 2011; Leschine, 2002) have indicated that the media can play multiple roles in risk debates, either a disseminator of expert-sourced, objective risk information or a watchdog of carefully constructed risk information, to the public. Onggo et al. (2014) have proposed three different roles that media can assume: it can lead public opinion and communicate an objective level of risk (an objective leader), it can follow public opinion by communicating the current, average public opinion (a public follower), or it can be a mixed leader-follower.

In the model the media agent becomes active at the start of contamination. This is not to say that prior to the revelation of contamination the media does not affect perceived risk within the public at all, but that the information on potential risk has not attracted much media and public attention to provoke extensive concern. This situation occurred in the 2008 Chinese milk scandal. A handful of parents had publicly questioned the quality of Sanlu's milk powder and made complaints to the regulators about kidney disease that their babies suffered (Associated Press, 2008; Fairclough, 2008; Gong and Liu, 2008). Their stories were picked up by a few media outlets yet unfortunately the warning signals were ignored by the regulators and the public. Afterwards the media disclosed the identification of kidney ailments among babies and contamination of baby milk powder with melamine by investigators and thus triggered strong public concern as well as public aversion to Sanlu milk products. Therefore, in the agent model media reporting about product contamination before its widespread outbreak is considered insignificant. The media communication is:

$$M(t) = \begin{cases} 0 & t < T_{start} \\ C(t) & t \geq T_{start} & \text{an objective leader} \\ \dfrac{1}{2}\left( C(t) + \dfrac{1}{N}\sum_{i=1}^{N} b_i(t-1) \right) & t \geq T_{start} & \text{a mixed leader-follower} \\ \dfrac{1}{N}\sum_{i=1}^{N} b_i(t-1) & t \geq T_{start} & \text{a public follower} \end{cases} \quad (5.9)$$

Then integrate the effect of media communication to the decision rule in equation (5.8) to form the final decision rule in the model:

$$b_i(t) = \alpha\left( \frac{1}{4}\left( b_i(t-1) + \frac{1}{K}\sum_{nj=1}^{K} b_{nj}(t) + e_i(t) + r(t) \right) \right) + \beta R_i(t) + \gamma M(t) \quad (5.10)$$

where $\alpha$, $\beta$, and $\gamma$ are the weight given to 'event discovery', 'recreancy' and the perception expressed in the 'media', $0 < \alpha < 1$, $0 < \beta < 1$, $0 < \gamma < 1$, and $\alpha + \beta + \gamma = 1$.

## 5.2.2 Simulation results

The simulation experiments are conducted using Repast Simphony. The agent model runs over a series of 20,000 periods with 1,000 public agents, a single producer agent, and a single media agent. Table 5.1 lists the input parameters and values used in the simulation. Some of these are social constants – parameters that would be expected to characterize an agent society. Ideally the values of these could be verified empirically, although in practice it seems very unlikely empirical information is actually available. Some of the parameters, however, define specific situations – for example, the high and low contamination levels. The value of these parameters is defined by the specific situation that the modeller wants to simulate. So the basis of these values is the modeller's view of a typical, representative or simply interesting situation.

Table 5.1 Input parameters and values used in the simulation of a perfect mixing model

| Input parameter | Value | Description |
|---|---|---|
| Maximum initial condition $I$ | $10^{-4}$ | Defines initial risk and recreancy belief |
| Number of neighbours $K$ | 4 | Number of neighbours in a perfectly mixed population |
| Low contamination level $C_{low}(t)$ | $10^{-4}$ | Level before and after crisis |
| High contamination level $C_{high}(t)$ | 0.2 | Level during the crisis |
| Contamination start period $T_{start}$ | 2000 | Time when the crisis starts |
| Contamination end period $T_{end}$ | 5999 | Time when the crisis ends |
| Risk perception threshold $B$ | 0.15 | Defines when a recall increases recreancy |
| Recreancy increment $D$ | 0.25 | Amount by which a recall increases recreancy |

| Recall voluntariness $v(t)$ | $\{0,1\}$ | Whether recall is voluntary or involuntary |
|---|---|---|
| Recreancy variation $E$ | 0.35 | Amount by which recall voluntariness changes recreancy |
| Weight of 'event discovery' $\lambda$ | 0.85 | Weight given to 'event discovery' in the partial model with recreancy |
| Weight of 'event discovery' $\alpha$ | 0.65 | Weight given to 'event discovery' in the full model |
| Weight of 'recreancy' $\beta$ | 0.05 | Weight given to 'recreancy' in the full model |

Figures 5.3 through 5.18 present the traces of agent risk perception in a single run that correspond to the stages by which the perfect mixing model is developed. Outcome variables are mean public risk perception over agents and over time and mean risk amplification (the gap between the objective risk and public risk perception) over agents and over time. Simulation result based on equation (5.1) is not presented as the basic decision rule simply produces convergence on the mean of the initial beliefs.

## *First stage: public response to experienced contamination in a perfectly mixed population*

Figure 5.3 illustrates the evolution of individual risk perceptions in a single run with a contamination incident introduced (equation (5.3)). Before contamination occurs, public risk perception stays at a very low level. And during contamination it surges to a relatively high level and produces exogenous peaks that reflect the changes in risk magnitude. This assumes that direct experience is an important foundation of perception and plays a critical role in shaping subjective risk estimates of public actors, and that the risk perceived by consumers varies with the information available to them. In addition, the results evidently demonstrate that the exogenous peaks occur around the time period when the contamination incident is coming to an end – in this case because the growth of risk perception has not stopped by the time the contamination ceases, there is a turning point when the ceasing occurs. The turning point is quite sharp, so the growth in risk perception is still positive just before the turning point, but the growth clearly declines as the incident progresses. It is also essentially monotonic: there are no transient reversals in the growth until the main turning point is reached. Hence, public risk response to external influence appears somewhat predictable, given knowledge of the model parameters.

Figure 5.3 shows risk attenuation rather than risk amplification – by the end of the growth phase, the risk perception (in terms of subjective probability of contamination) is still less than the objective risk (the actual contamination probability). But it is hard to say whether this is the case for all levels of contamination, so two extreme values are examined, as shown in

Figure 5.4 and Figure 5.5. Risk amplification occurs if the contamination level is very low (Figure 5.4), and risk also becomes attenuated if the contamination level is very high (Figure 5.5). This indicates that risk amplification only occurs if the contamination level is below a certain threshold. The fluctuation of standard deviation in Figure 5.4 suggests that low contamination raises the disagreement among individuals' responses to the contamination crisis. Furthermore, it has been observed that a former model with longer period of contamination generates risk amplification with lower amplification threshold. In Chapter 7 both the contamination level and contamination duration are parameterised to inspect the sensitivity of the model to these parameters.
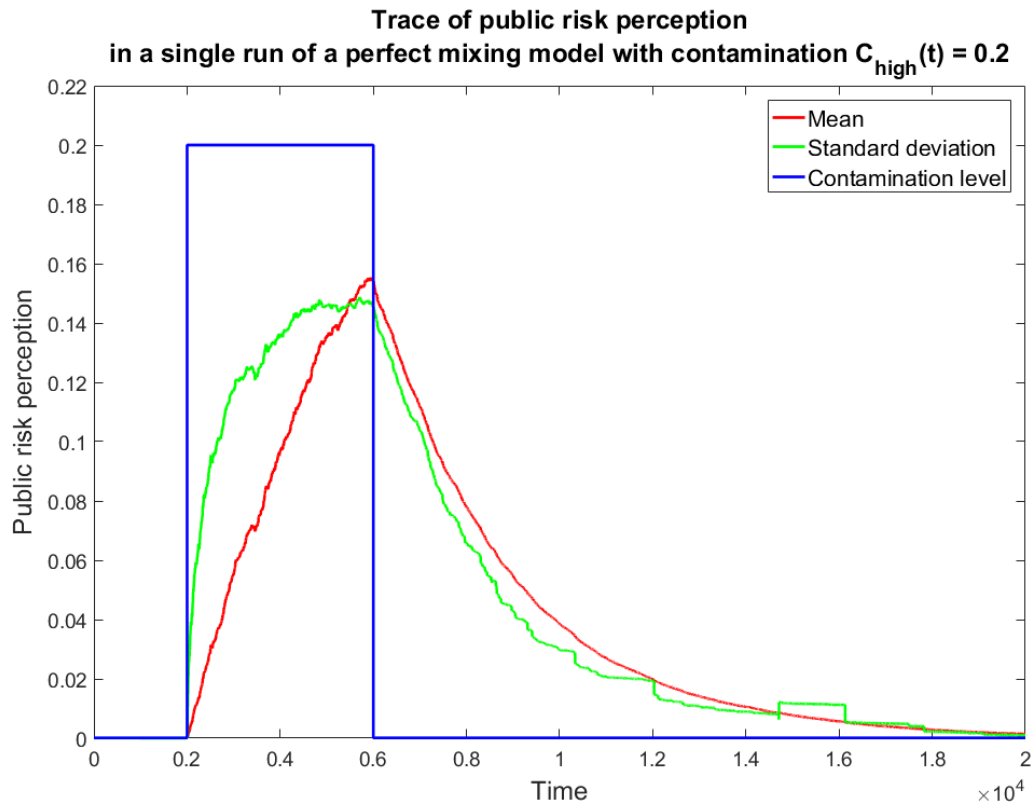


Figure 5.3 Trace of public risk perception in a single run of a perfect mixing model with contamination $C_{high}(t) = 0.2$
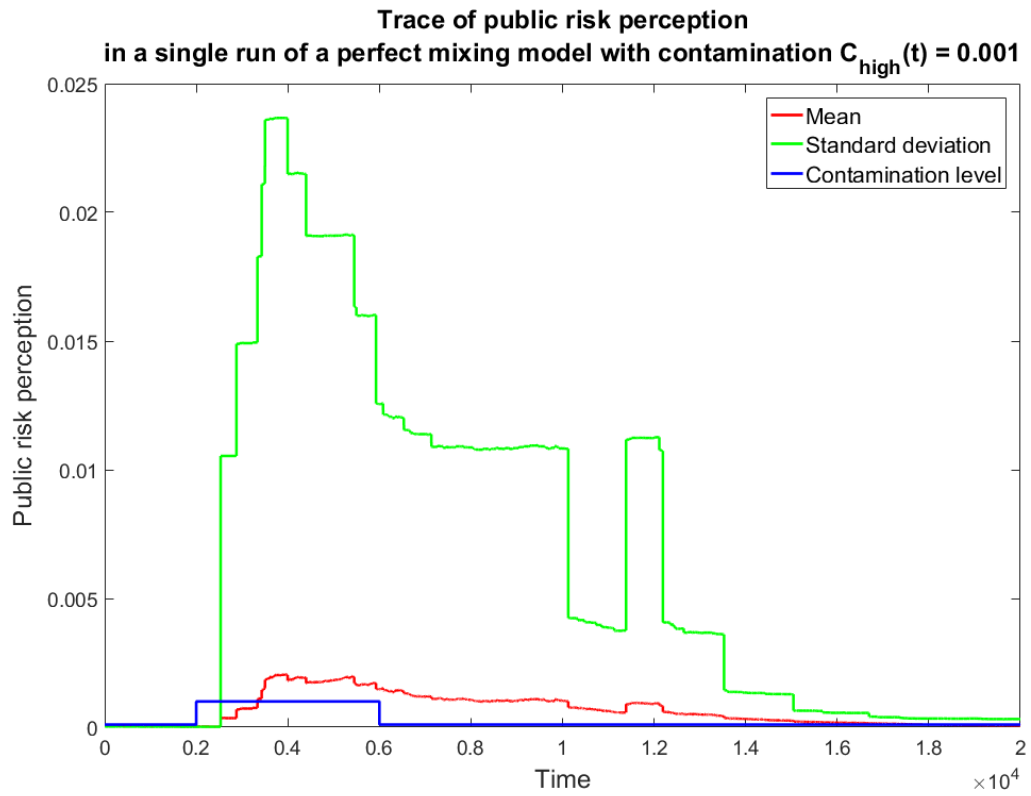
Figure 5.4 Trace of public risk perception in a single run of a perfect mixing model with contamination $C_{high}(t) = 0.001$
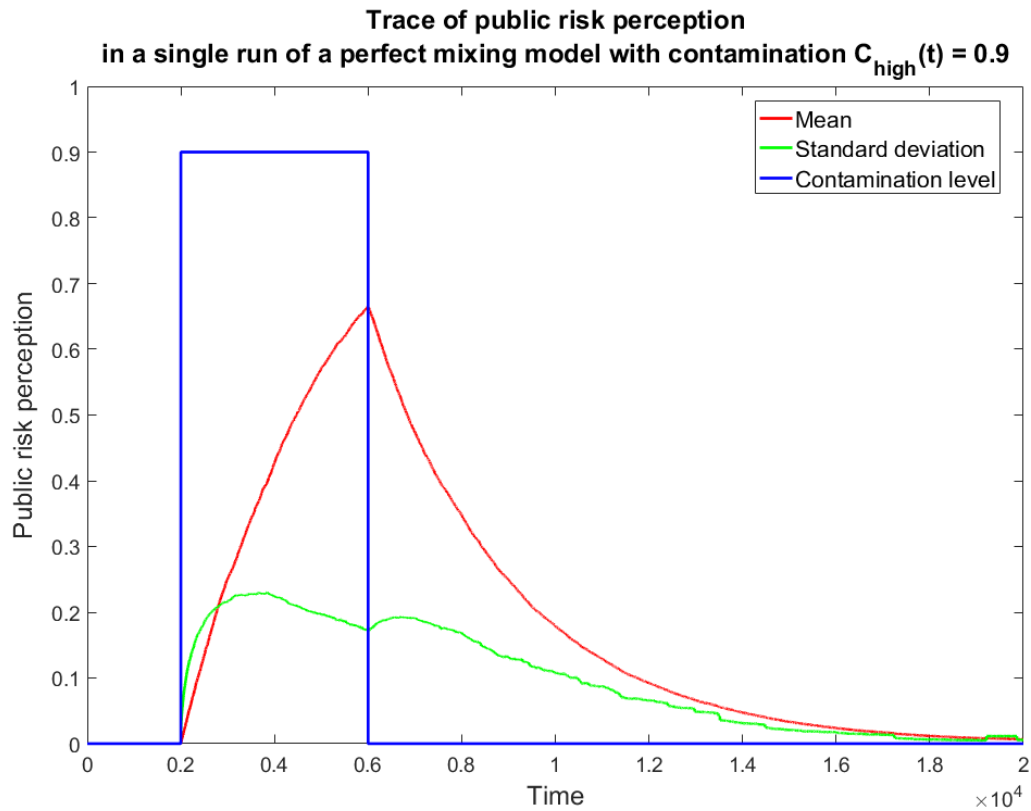


Figure 5.5 Trace of public risk perception in a single run of a perfect mixing model with contamination $C_{high}(t) = 0.9$

## Second stage: addition of a product recall event in a perfectly mixed population

Figure 5.6 demonstrates the trace of agent risk perception in a single run when product recall is also considered as an exogenous effect (equation (5.4)). It shows that publicity of product recall triggers a very strong growth of risk perception – this is as expected from the model as recall is assumed to associate with a significant effect on risk perception. More importantly, there is a considerable discrepancy between mean public risk perception and the contamination level – there is evidently risk amplification. In the model the consumers' decision rule gives a value to the recall element of 0 or 1, not the objective contamination probability. Therefore, the public estimate of the risk can become amplified above the objective level.
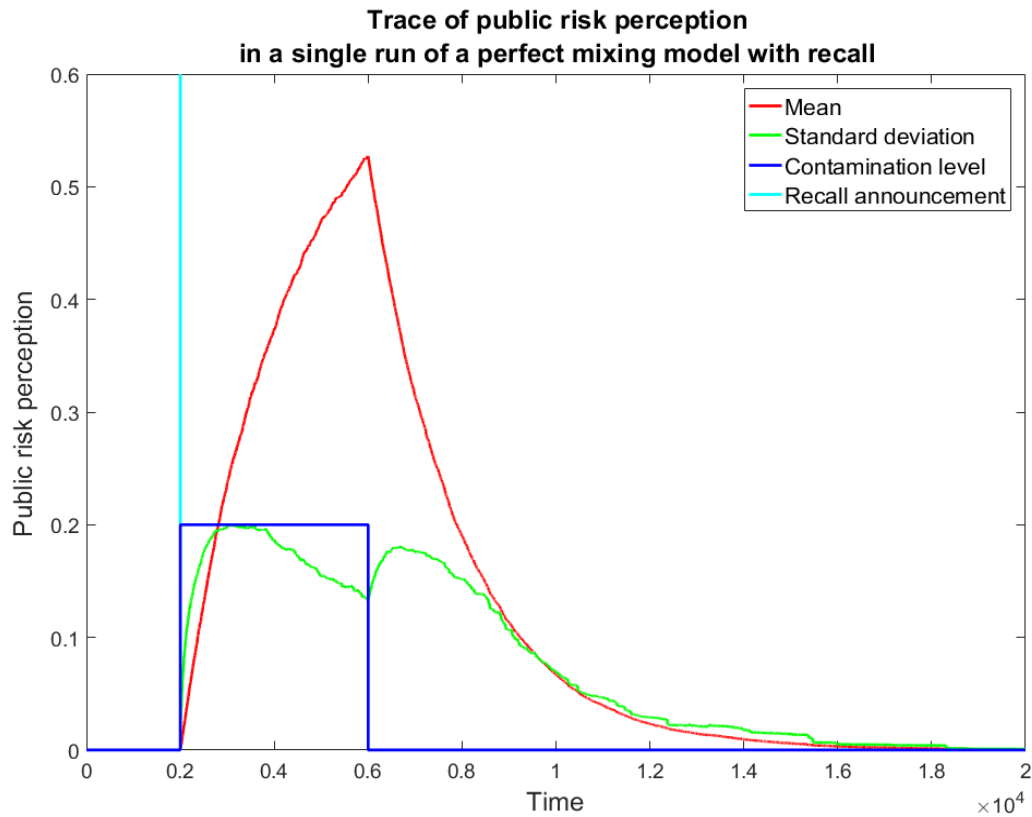


Figure 5.6 Trace of public risk perception in a single run of a perfect mixing model with recall ( $a(t = 2003) = 1$ )

Figure 5.7 presents the comparison between model with contamination (Figure 5.3 on the left) and model with product recall (Figure 5.6 on the right). After contamination is removed, the decline rate is much faster in Figure 5.6 than in Figure 5.3. This is because the absence of product recall facilitates the relaxation of risk perception from a fairly high level to a very low
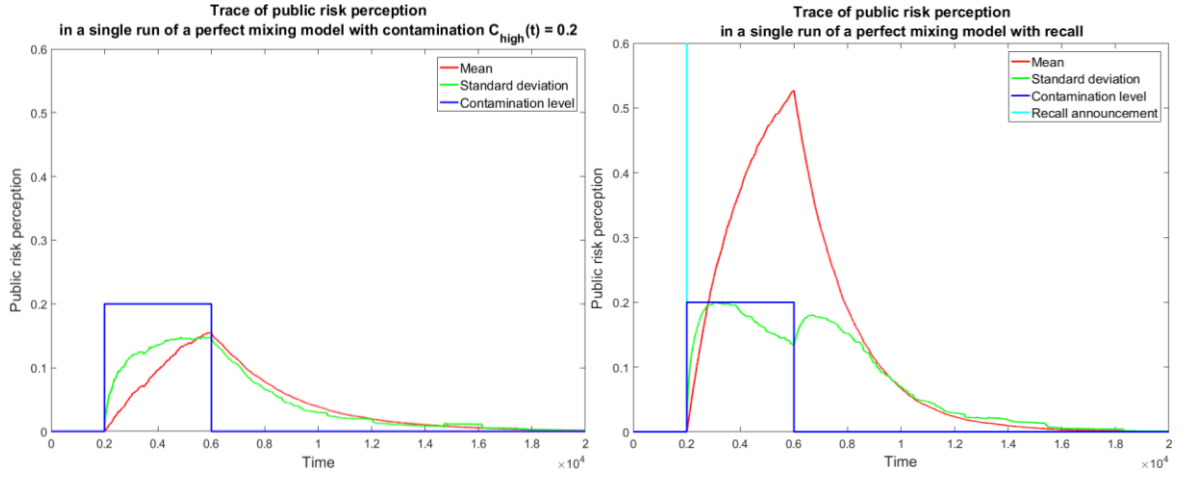
level.



Figure 5.7 Comparison between model with contamination (Figure 5.3 on the left) and model with recall (Figure 5.6 on the right)

## *Third stage: addition of recreancy in a perfectly mixed population*

Figure 5.8 shows the trace of public risk perception and recreancy belief in a single run with a voluntary recall (equation (5.8) with $v(t)=1$). Comparison between model with recall (Figure 5.6 on the left) and model with voluntary recall (Figure 5.8 on the right) is presented in Figure 5.9. A $t$-test indicates that there is a significant difference between Figure 5.6 and Figure 5.8 in peak mean risk perception ($t(df=950.297)=428.738$ and $p<0.001$) and residual mean risk perception ($t(df=611.801)=4,668.792$ and $p<0.001$) across 500 runs with a significance level of 0.05. Compared with Figure 5.6, Figure 5.8 exhibits a relatively slow growth followed by a relatively slow decay, and there is a lower degree of risk amplification. This is because voluntary recall decreases agents' recreancy belief in the producer and thus positively affects their risk beliefs. In other words, the indirect effect (i.e. recreancy) of a voluntary recall can somewhat diminish its direct effect (i.e. product recall information) and thus lessens consumers' perceptions of risk.

In particular, in Figure 5.8 recreancy belief surges to a high level after the recall is completed and then becomes level. In the model when there is no recall in force, an agent will increase its recreancy belief by some amount if the risk it perceives is above some threshold (which is set as 0.15) and keep its recreancy belief unchanged otherwise. Therefore, recreancy belief continues to increase as risk perception stays above the threshold and becomes stabilised when risk perception falls below the threshold. And the constant high level of recreancy is the reason why risk perception stabilises at a higher level in Figure 5.8 than in Figure 5.6.
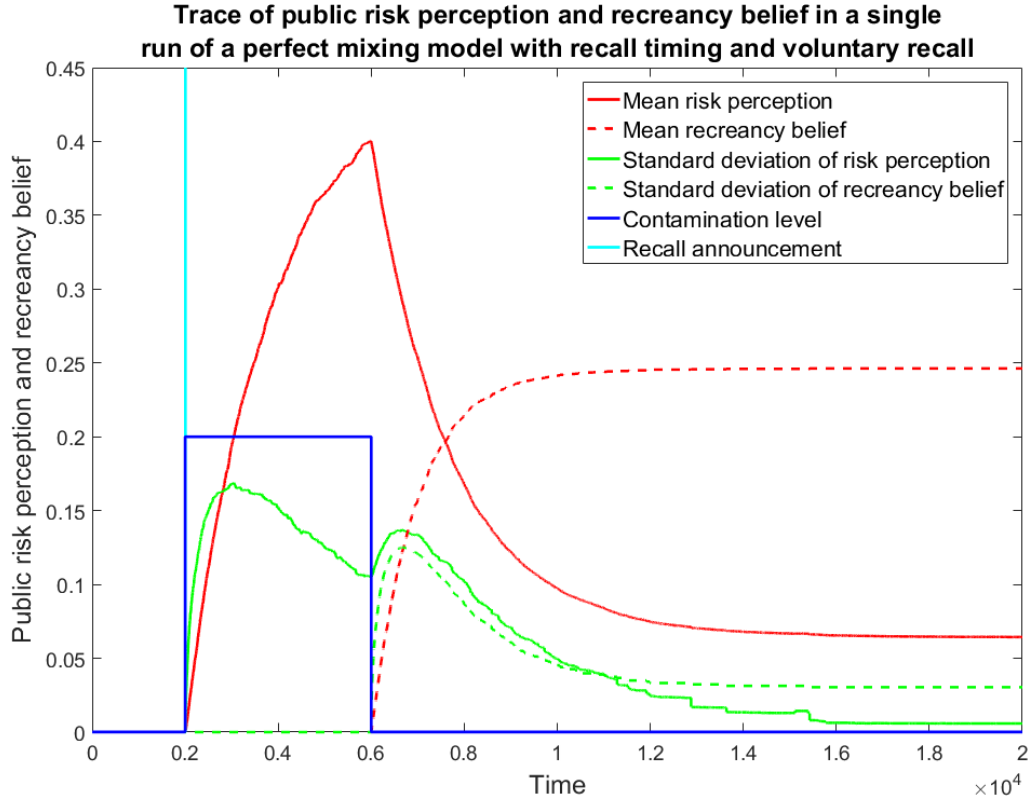
Figure 5.8 Trace of public risk perception and recreancy belief in a single run of a perfect mixing model with recall timing and voluntary recall ( $a(t=2005)=1$, $v(t)=1$ )



Figure 5.9 Comparison between model with recall (Figure 5.6 on the left) and model with voluntary recall (Figure 5.8 on the right)

Figure 5.10 shows the trace of mean risk belief and recreancy belief over time with an involuntary recall (equation (5.8) with $v(t)=0$ ). Comparison between model with recall (Figure 5.6) and model with involuntary recall (Figure 5.10) is given in Figure 5.11. Figure 5.6 and Figure 5.10 are statistically different in peak risk perception ( $t(df=965.768)=132.019$ and $p<0.001$ ) and residual risk perception

$(t(df = 522.098) = 5,276.382$ and $p < 0.001)$ over 500 runs with a significance level of 0.05.

Figure 5.11 demonstrates that involuntary recall generates a lower level of risk amplification and a much higher residue of concern. This is what the modeller expects based on the decision rule. The explanation for the lower amplification is that, involuntary recall increases recreancy belief, but risk perceived from recreancy is much lower than that from recall information, so involuntariness to some extent reduces the amplification effect of recall information and leads to a lower degree of amplification. There is no recall after the crisis, so recreancy belief continues to increase until risk perception drops to a certain threshold, resulting in a higher residual risk perception after the crisis.



Figure 5.10 Trace of public risk perception and recreancy belief in a single run of a perfect mixing model with recall timing and involuntary recall ($a(t = 2001) = 1, v(t) = 0$)
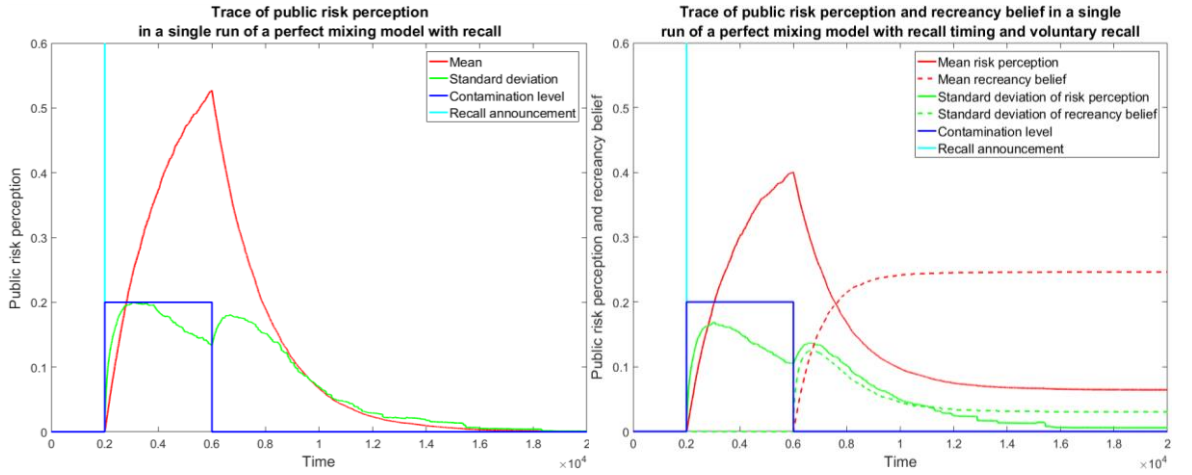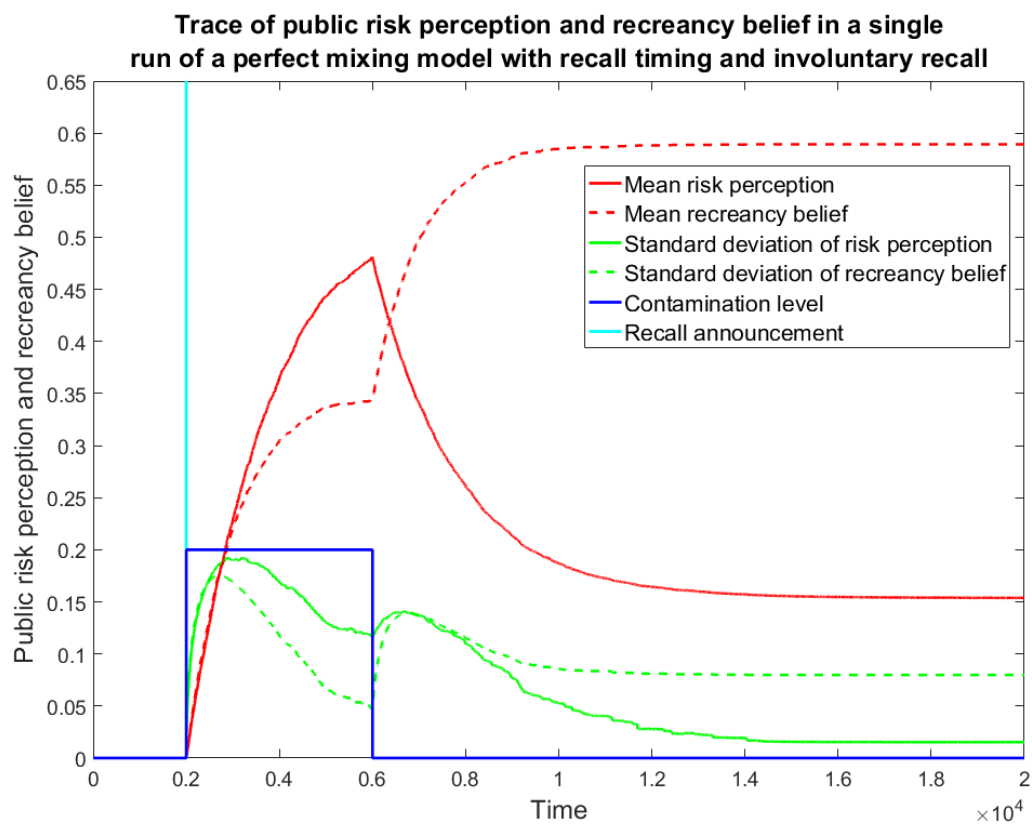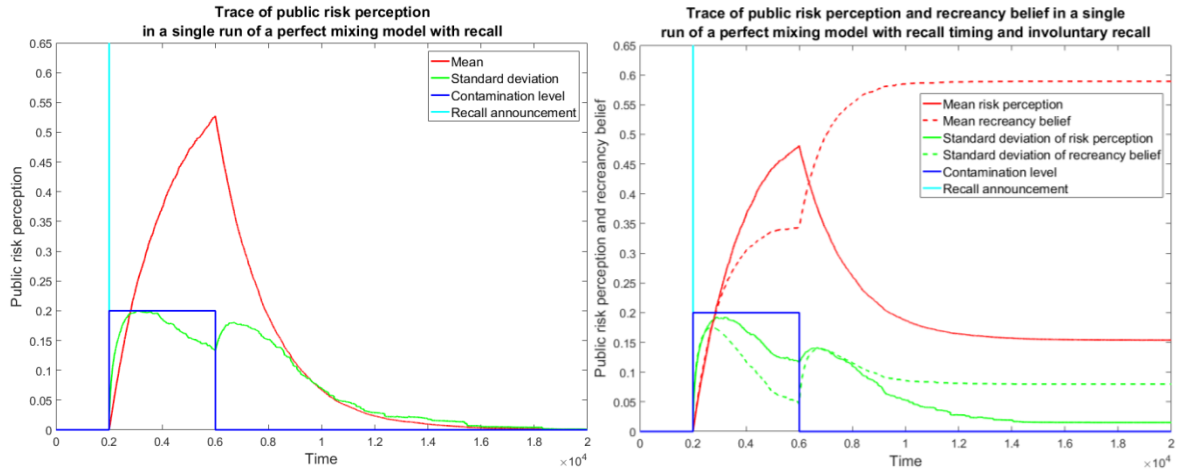
Figure 5.11 Comparison between model with recall (Figure 5.6 on the left) and model with involuntary recall (Figure 5.10 on the right)

Figure 5.12 shows the comparison between model with voluntary recall (Figure 5.8 on the left) and model with involuntary recall (Figure 5.10 on the right). There is a statistically significant difference between them in terms of peak mean risk perception ( $t(df = 996.147) = 326.958$ and $p < 0.001$ ), peak mean recreancy belief ( $t(df = 684.217) = 2,894.413$ and $p < 0.001$ ), and post-crisis risk perception ( $t(df = 692.890) = 2,846.114$ and $p < 0.001$ ) over 500 runs with a significance level of 0.05. This is in line with the decision rules in the model. During the crisis an agent increases its recreancy belief when the producer implements an involuntary recall and decreases its recreancy belief when a recall is made voluntarily. The magnitude of risk amplification is therefore higher in Figure 5.10 than in Figure 5.8. Also, Figure 5.10 displays a higher stabilised risk perception and recreancy belief after the crisis. This is mainly due to the reason that in an involuntary recall event it takes a longer time to reduce agent risk beliefs to the threshold that defines when a recall increases recreancy, leading to a higher recreancy belief and residual risk perception. In reality, when an involuntary recall comes into force, consumers tend to feel that the company is not socially responsible in dealing with the crisis, to have a more negative impression of the company, and to perceive the product as more dangerous.
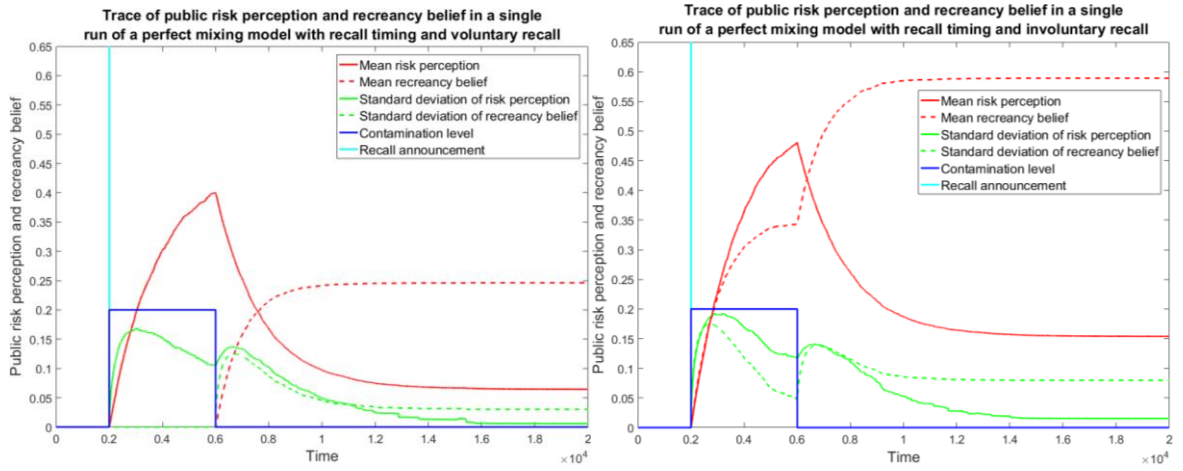
Figure 5.12 Comparison between model with voluntary recall (Figure 5.8 on the left) and model with involuntary recall (Figure 5.10 on the right)

## *Fourth stage: addition of media in a perfectly mixed population*

The effects of roles that the media assumes on public perceived risk are examined in the light of voluntary recall and involuntary recall. Figure 5.13 demonstrates the trace of individual agent beliefs when the producer makes a recall voluntarily and the media acts as an objective leader, a mixed leader-follower, and a public follower, respectively (equation (5.10) with $v(t)=1$). Risk amplification – that is, a collective perception that exceeds the objective risk level – occurs regardless of the role that media assumes. The objectivity of media coverage appears to be inversely related to risk amplification: a media that simply follows public opinion is associated more strongly with exaggerated risk perceptions than an objective one. Another insight is that for all of the three roles of media, risk amplification seems to decrease with the contamination level. Particularly, risk amplification will increase significantly if the contamination level is very low (Figure 5.14) and decease considerably if the contamination level is very high (Figure 5.15). Sensitivity analysis presented in Chapter 7 explores how contamination level affects peak risk amplification.

It is significant that when the crisis finishes, and, the contamination has fallen to its original level, when the media is a public follower the public risk perception remains very high – it is not corrected by the reduction in objective risk. So risk amplification and the role of media are important not just at the start of a crisis but at the end. It will be hard for crisis managers to end a crisis if the media is a strong follower of public opinion.

Figure 5.13 Trace of public risk perception in a single run of a full perfect mixing model with voluntary recall ( $a(t=2008)=1$, $v(t)=1$ ) and contamination $C_{high}(t)=0.2$



Figure 5.14 Trace of public risk perception in a single run of a full perfect mixing model with voluntary recall ( $a(t=2008)=1$, $v(t)=1$ ) and contamination $C_{high}(t)=0.05$

**Trace of public risk perception in a single run of a full perfect mixing model with voluntary recall and contamination C$_{high}$(t) = 0.95**

Figure 5.15 Trace of public risk perception in a single run of a full perfect mixing model with voluntary recall ( $a(t=2008)=1$, $v(t)=1$ ) and contamination $C_{high}(t)=0.95$

Figure 5.16 shows that if the producer issues a recall involuntarily, risks will be intensified regardless of the role of media (equation (5.10) with $v(t)=0$ ). Both risk amplification and residual risk perception are higher than in the case where a recall is made voluntarily. There is an inverse relationship between the objectivity of media coverage and risk amplification. Figure 5.16, Figure 5.17, and Figure 5.18 show that social risk amplification decreases with the level of contamination.

The model does not explore possibilities in which the media leads public opinion, but leads it with a belief that is different from the objective level of risk. A theory that claims the media will communicate exaggerated stories in order to sell more newspapers or TV viewing might lead with a very high risk belief.
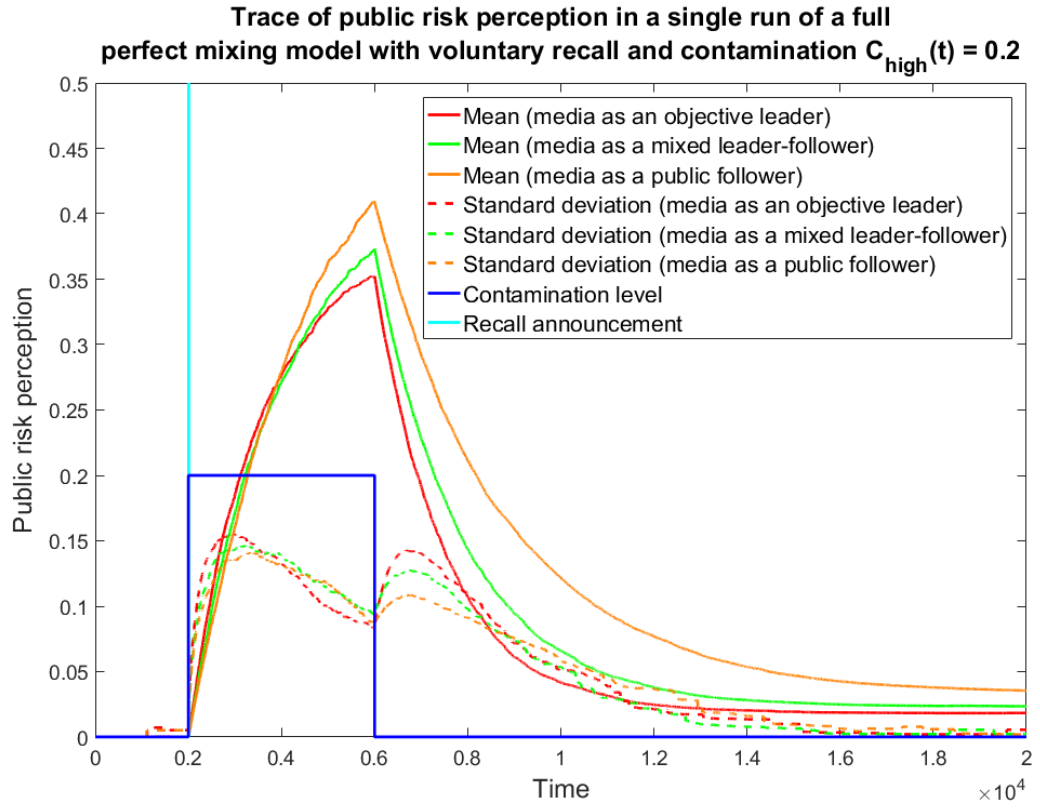
Figure 5.16 Trace of public risk perception in a single run of a full perfect mixing model with involuntary recall ( $a(t = 2003) = 1$ , $v(t) = 0$ ) and contamination $C_{high}(t) = 0.2$
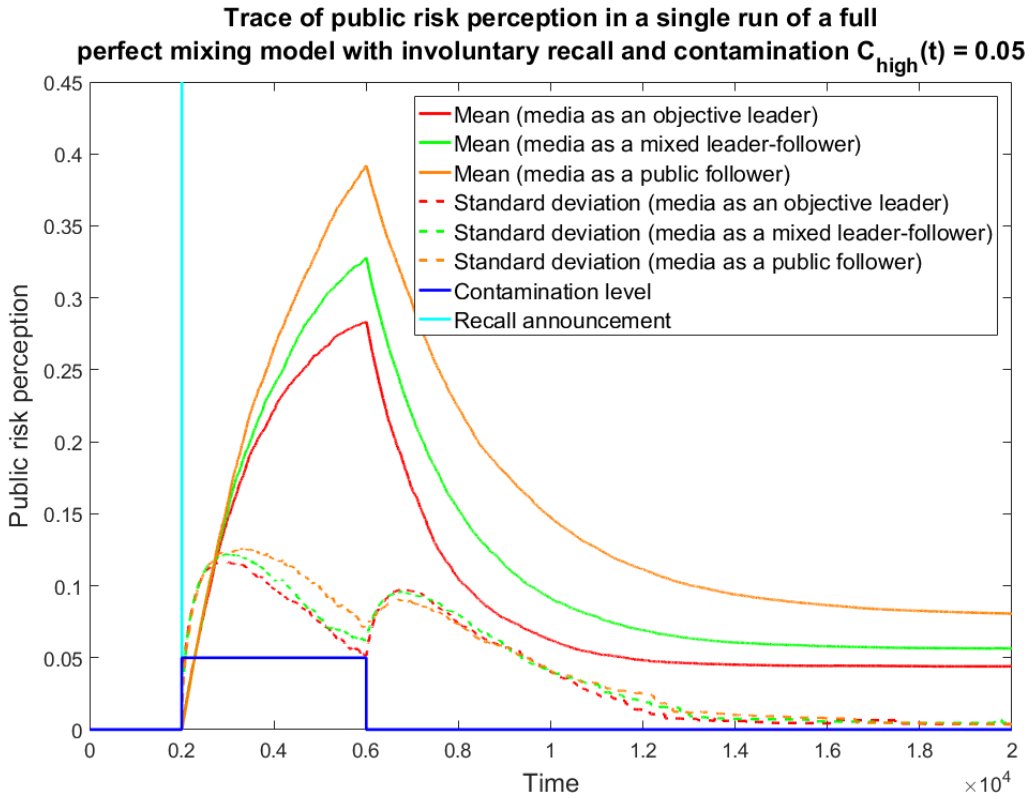


Figure 5.17 Trace of public risk perception in a single run of a full perfect mixing model with involuntary recall ( $a(t = 2003) = 1$ , $v(t) = 0$ ) and contamination $C_{high}(t) = 0.05$
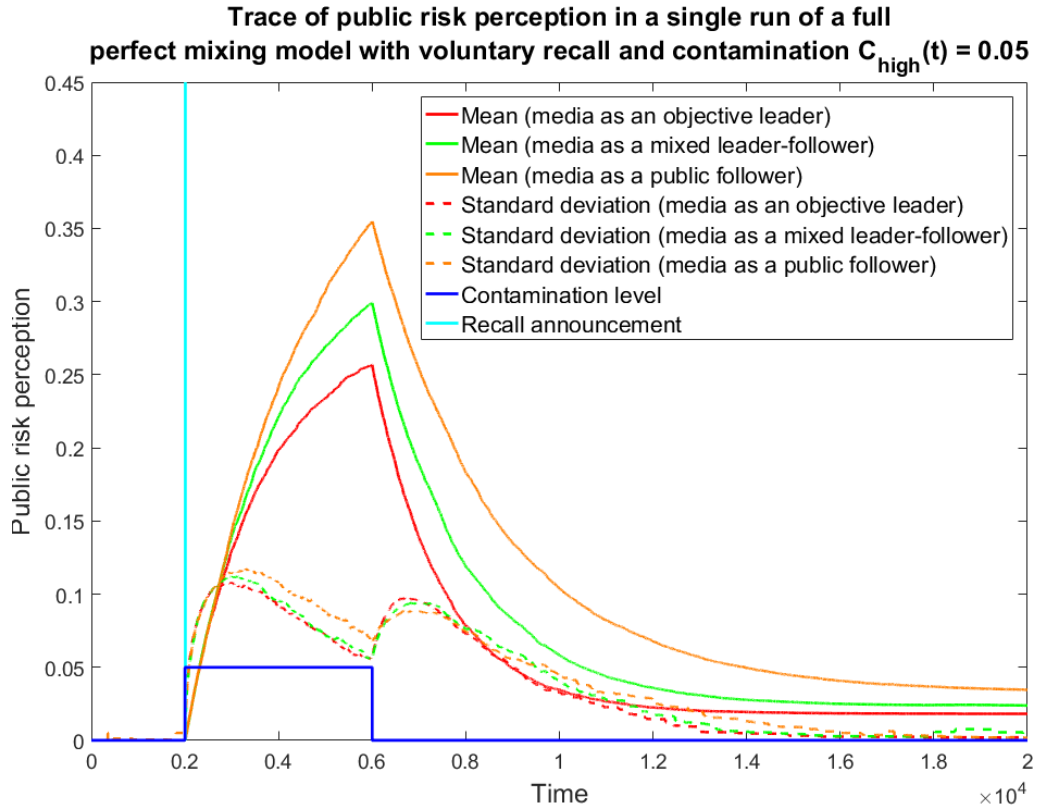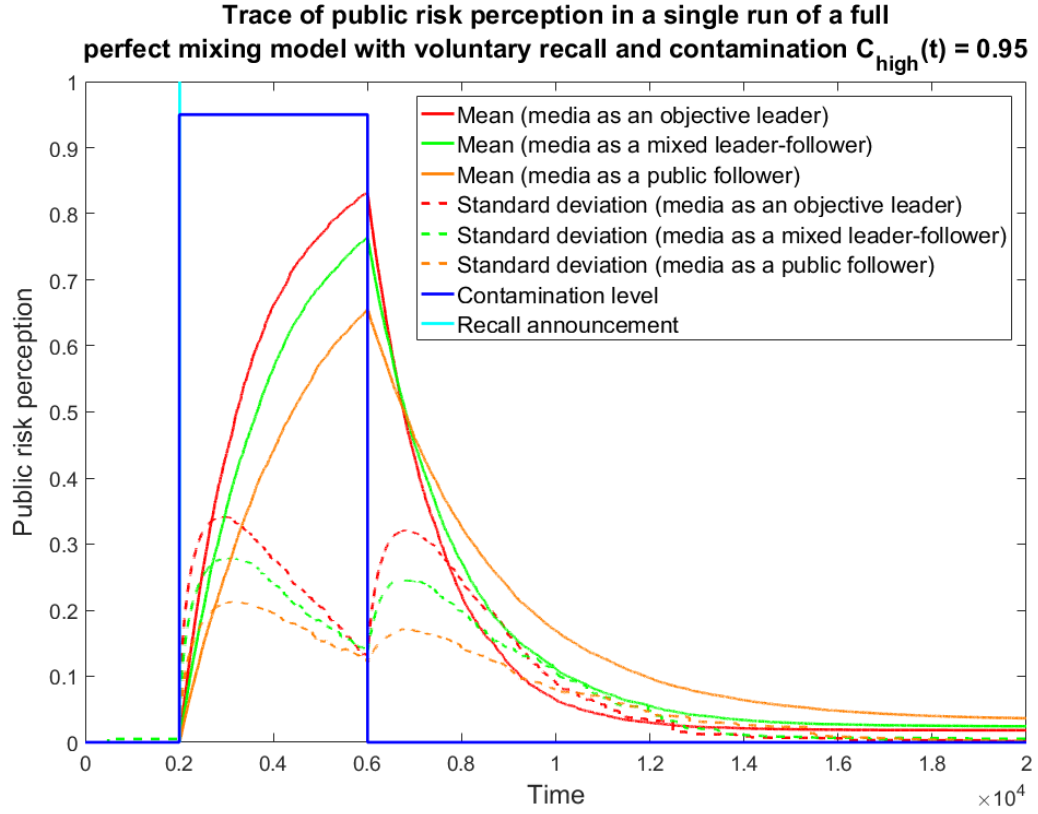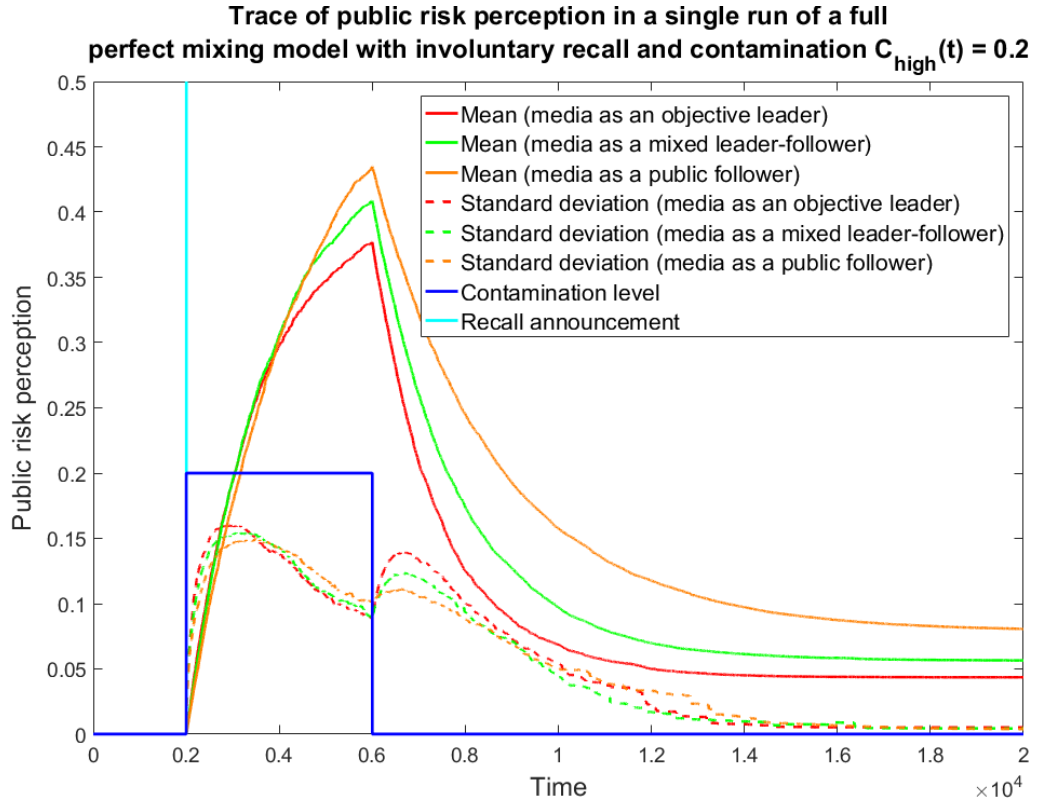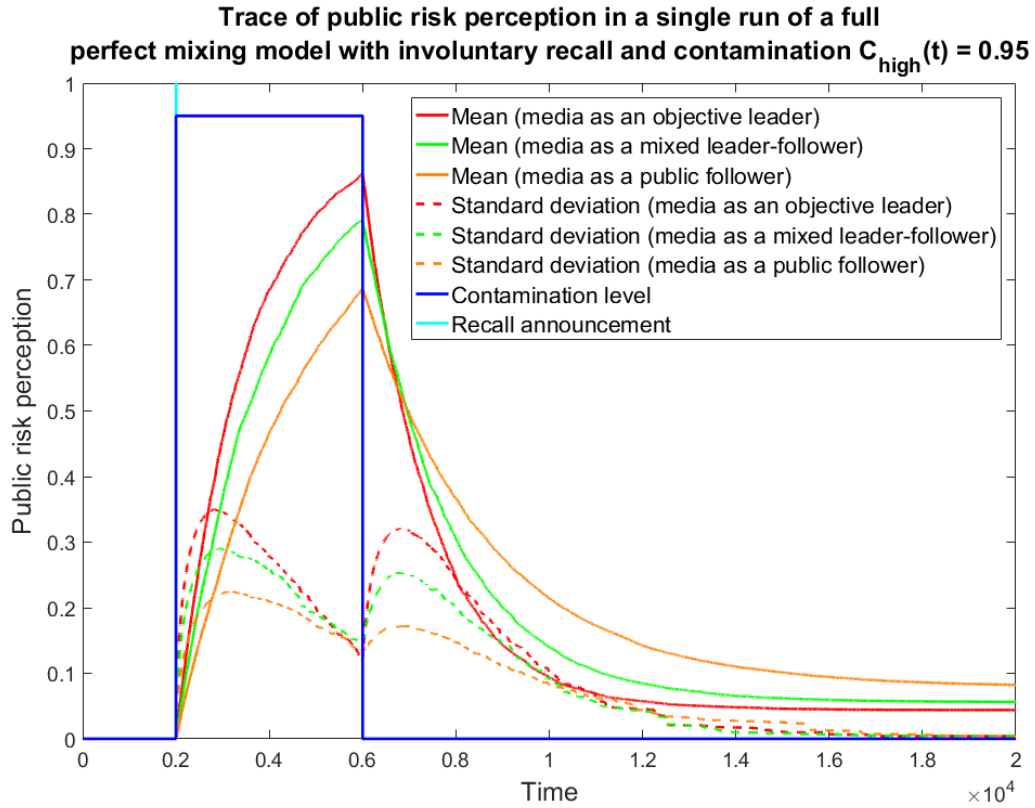
Figure 5.18 Trace of public risk perception in a single run of a full perfect mixing model with involuntary recall ( $a(t=2003)=1$ , $v(t)=0$ ) and contamination $C_{high}(t)=0.95$

# 5.3 A small-world network model

In this model public agents communicate with each other within a small-world network borrowed from Watts and Strogatz (1998). This is based on the same conceptual model in Figure 5.2, but unlike the perfect mixing model, agents only interact with the other agents to which they are connected in this pre-determined network. Each agent is initially connected to its $K$ nearest neighbours in a regular lattice, and each link is randomly rewired with a probability $P$. For the purpose of this model, of a single event, the network is fixed. Table 5.2 gives the input parameters and values used for simulating such a model.

Table 5.2 Input parameters and values used in the simulation of a small-world network model

| Input parameter | Value | Description |
|---|---|---|
| Maximum initial condition $I$ | $10^{-4}$ | Defines initial risk and recreancy belief |
| Number of neighbours $K$ | 4 | Number of neighbours in initial lattice |
| Rewiring probability $P$ | 0.5 | Probability of reconnecting a lattice edge |
| Low contamination level $C_{low}(t)$ | $10^{-4}$ | Level before and after crisis |
| High contamination level $C_{high}(t)$ | 0.2 | Level during the crisis |

| | | |
|---|---|---|
| Contamination start period $T_{start}$ | 2000 | Time when the crisis starts |
| Contamination end period $T_{end}$ | 5999 | Time when the crisis ends |
| Risk perception threshold $B$ | 0.15 | Defines when a recall increases recreancy |
| Recreancy increment $D$ | 0.25 | Amount by which a recall increases recreancy |
| Recall voluntariness $v(t)$ | $\{0,1\}$ | Whether recall is voluntary or involuntary |
| Recreancy variation $E$ | 0.35 | Amount by which recall voluntariness changes recreancy |
| Weight of 'event discovery' $\lambda$ | 0.85 | Weight given to 'event discovery' in the partial model with recreancy |
| Weight of 'event discovery' $\alpha$ | 0.65 | Weight given to 'event discovery' in the full model |
| Weight of 'recreancy' $\beta$ | 0.05 | Weight given to 'recreancy' in the full model |

Figures 5.19 through 5.30 show the traces of individual agent beliefs in a single run following the stages of building the model.

## *First stage: public response to experienced contamination in a small-world network*

Figure 5.19 shows the trace of public risk perception in a small-world network model with a contamination event (equation (5.3)). Like the perfect mixing model (see Figure 5.3), contamination does not lead to amplification of risk – there is a certain level of risk attenuation, and risk perception peaks around the termination of contamination. But the small-world network model produces lower peaks in risk perception compared with the perfect mixing model. This indicates that spread of risk information in a small-world network could to some extent reduce public risk estimates in a context in which only social interaction and direct experience contribute to belief update.

Different contamination levels are examined to look at how peak mean risk perception varies with contamination level, as shown in Figure 5.20 and Figure 5.21. Figure 5.19, 5.20, and 5.21 demonstrate that high contamination level associates with a relatively rapid increase of risk perception. It seems that the degree of risk amplification decreases with the level of contamination. Comparison of the three figures in standard deviation suggests that disagreement in risk beliefs among individuals is more likely to emerge when contamination stays at a lower level during the crisis. This is because a low contamination level is accompanied by a low probability of an agent experiencing the harm and a limited access of an agent to related risk information. Moussaïd (2013) pointed out that individuals express extreme opinions when they are less informed of associated risks. They tend to absorb

messages that agree with their own perceptions and neglect those that strongly disagree with their current views.
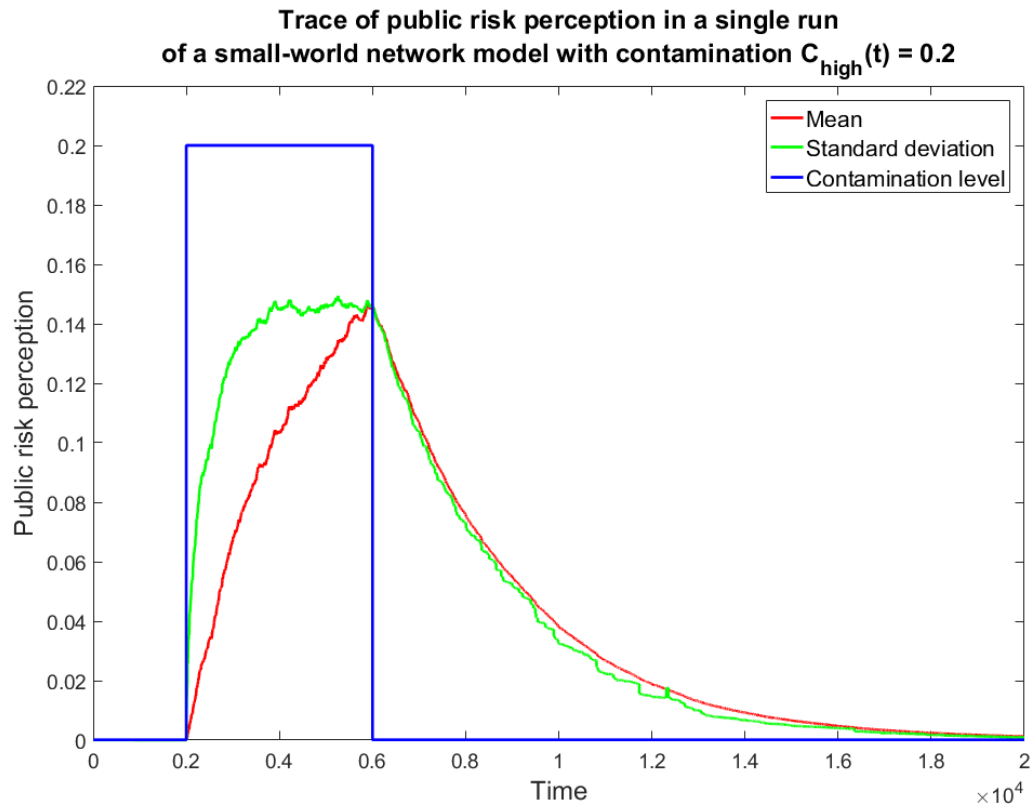


Figure 5.19 Trace of public risk perception in a single run of a small-world network model with contamination $C_{high}(t) = 0.2$
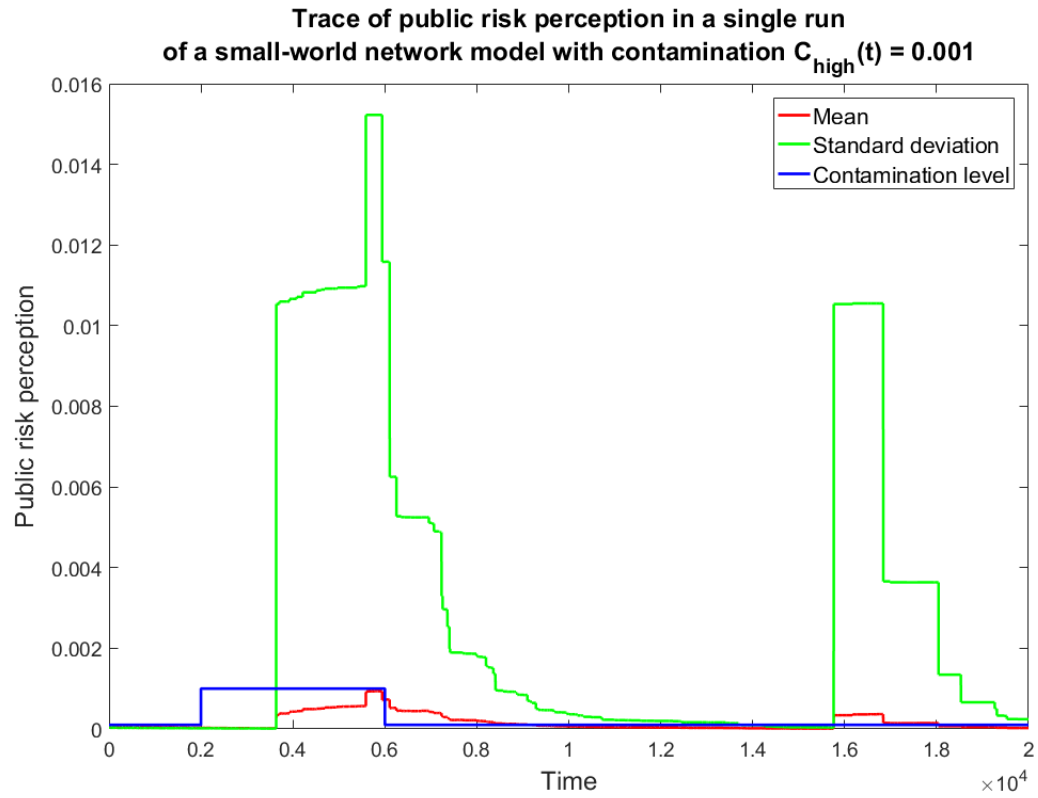
Figure 5.20 Trace of public risk perception in a single run of a small-world network model with contamination $C_{high}(t) = 0.001$
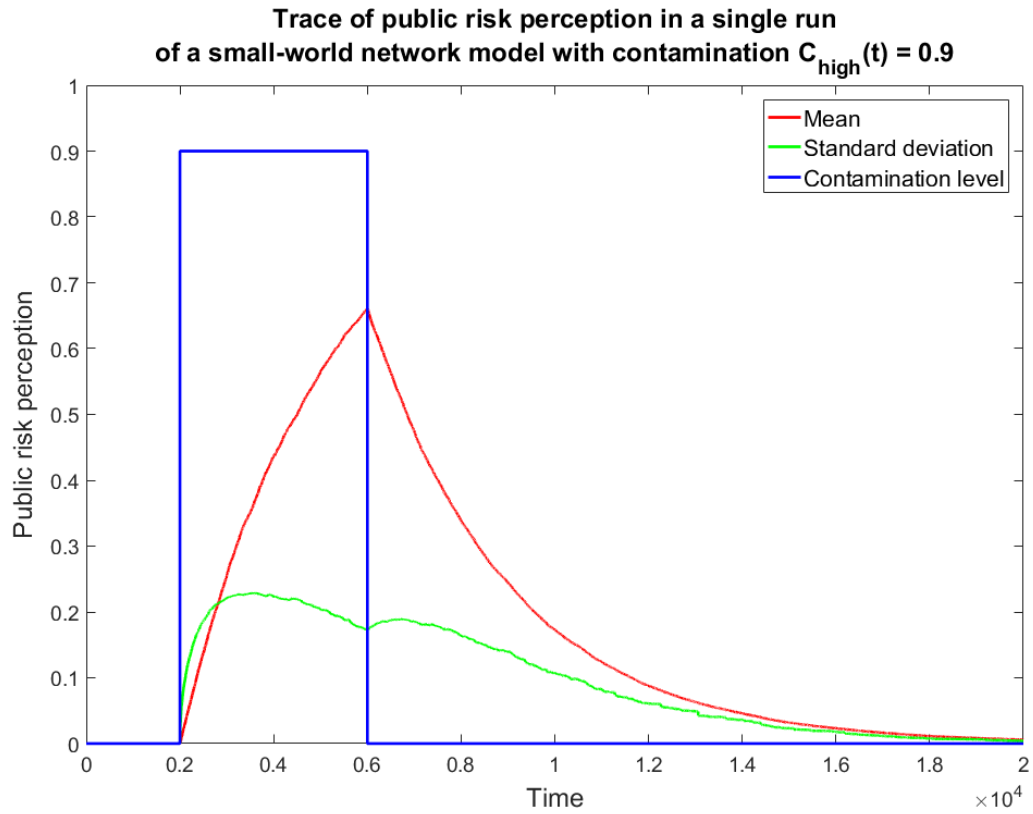


Figure 5.21 Trace of public risk perception in a single run of a small-world network model with contamination $C_{high}(t) = 0.9$

## *Second stage: addition of a product recall event in a small-world network*

Figure 5.22 shows the mean risk belief in a single run of the small-world network model with product recall (equation (5.4)). As is evident from the figure, there is a sharp increase, followed by a relatively rapid relaxation, of collective risk response. Agents perceive danger associated with the product from the recall information and their estimates of risk increase, giving rise to amplification of the risk. The relatively large magnitude of risk amplification is because the model assumes that the risk agents perceive from product recall is 1 when they hear the recall. In reality, the risk probably falls on a continuous scale and is heterogeneous across the population.
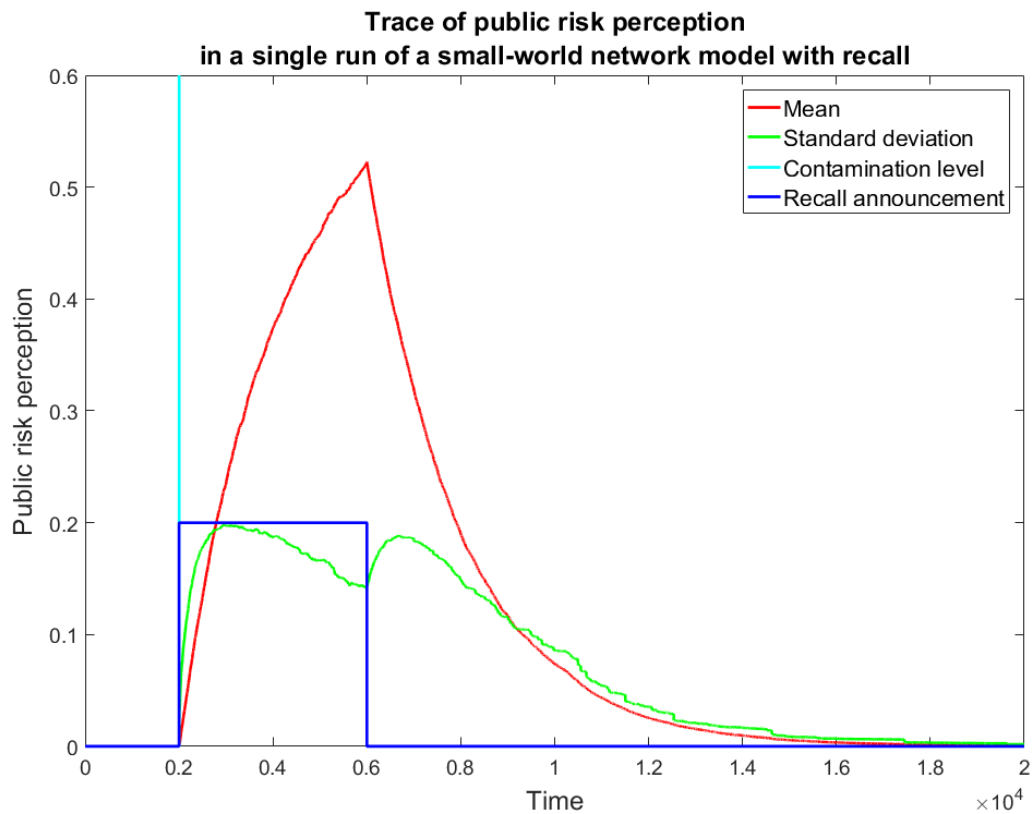


Figure 5.22 Trace of public risk perception in a single run of a small-world network model with recall ( $a(t=2003)=1$ )

## *Third stage: addition of recreancy in a small-world network*

As shown in Figure 5.23 (equation (5.8) with $v(t)=1$) and Figure 5.24 (equation (5.8) with $v(t)=0$), voluntary and involuntary recalls produce basically the same qualitative pattern of collective risk response, but an involuntary recall brings about a relatively higher level of risk

amplification during the crisis as well as a higher residue of concern after the crisis than a voluntary recall. There is little difference between them and figures (Figure 5.8 and Figure 5.10) produced by the perfect mixing model, so analysis of the simulation results are not presented here.

The existing simulation results cannot be used to explore the influence of recall timing on risk perception, since they are just generated from a single run of the model. Multiple replications are carried out in Chapter 7 to investigate the effect of relevant parameters on social risk amplification.
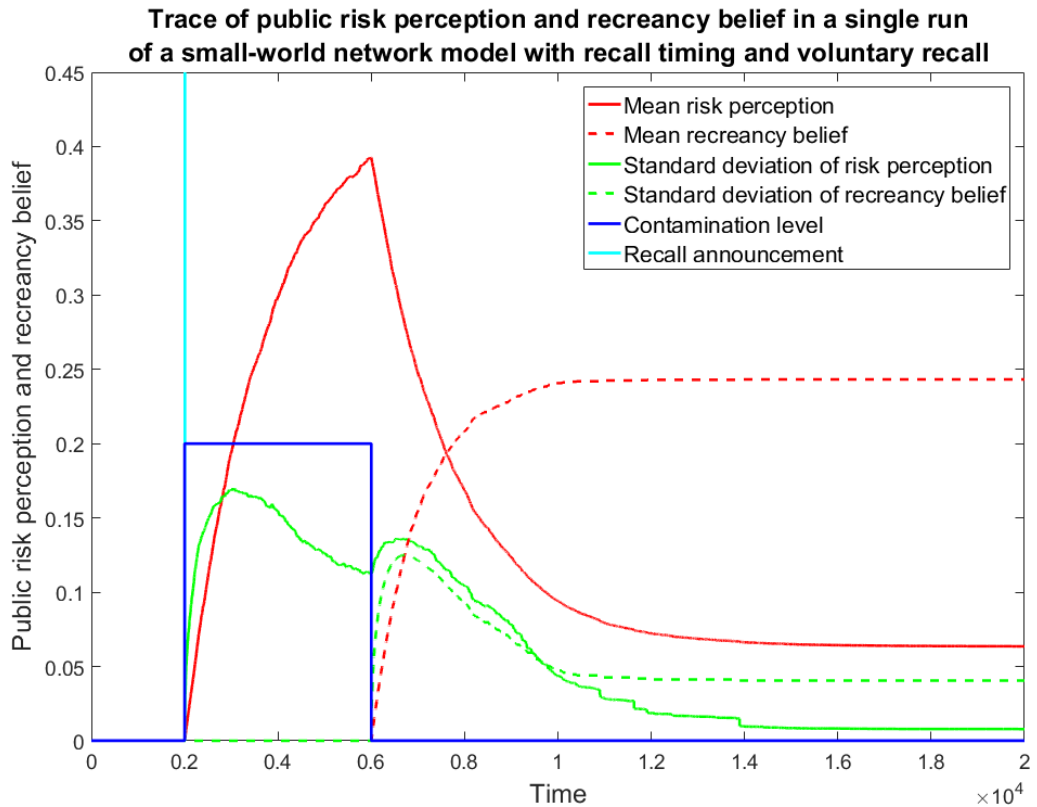


Figure 5.23 Trace of public risk perception and recreancy belief in a single run of a small-world network model with recall timing and voluntary recall ( $a(t=2005)=1$, $v(t)=1$ )
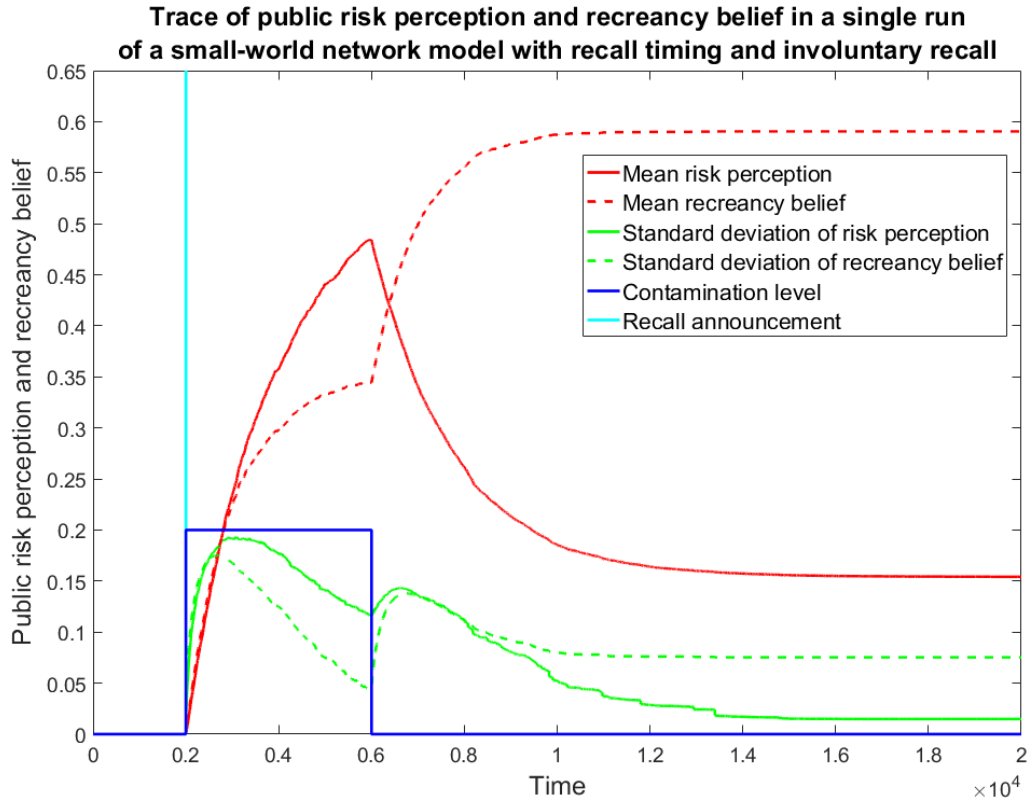
Figure 5.24 Trace of public risk perception and recreancy belief in a single run of a small-world network model with recall timing and involuntary recall ( $a(t=2001)=1$, $v(t)=0$ )

## *Fourth stage: addition of media in a small-world network*

Figure 5.25 shows the trace of agent risk beliefs when the media assumes three different roles in a voluntary recall crisis (equation (5.10) with $v(t)=1$). The results demonstrate that risk amplification occurs regardless of the role that the media is undertaking. The objectivity of media coverage is inversely related to the amplification of risk. After the crisis is solved, public risk perception falls to a stable level after a certain period of time. The objectivity of media communicated risk is inversely related to the time taken to reach the stable point and the level of stabilised risk perception: the more objective the media coverage, the less time it takes to stabilise, and the lower the residue of concern. It is important that risk managers pay special attention to residual risk perception if the media is a strong follower of public opinion.

Figure 5.26 and Figure 5.27 depict the traces of public risk perception at different contamination levels. It appears that the contamination level is inversely related to the discrepancy between public risk perception and the objective risk. The three figures exhibit approximately, but not exactly, smooth standard deviation after the crisis finishes, suggesting that individual risk perceptions become homogeneous in the long run. Compared with the perfect mixing model (Figure 5.13, Figure 5.14, and Figure 5.15), the small-world network

model exhibits a slightly lower degree of risk amplification. This indicates that social ties associated with a network can mitigate the negative influence of product recall on public risk perception (i.e. product recall increases public risk perception) to a very small extent.



Figure 5.25 Trace of public risk perception in a single run of a full small-world network model with voluntary recall ( $a(t = 2008) = 1$, $v(t) = 1$ ) and contamination $C_{high}(t) = 0.2$
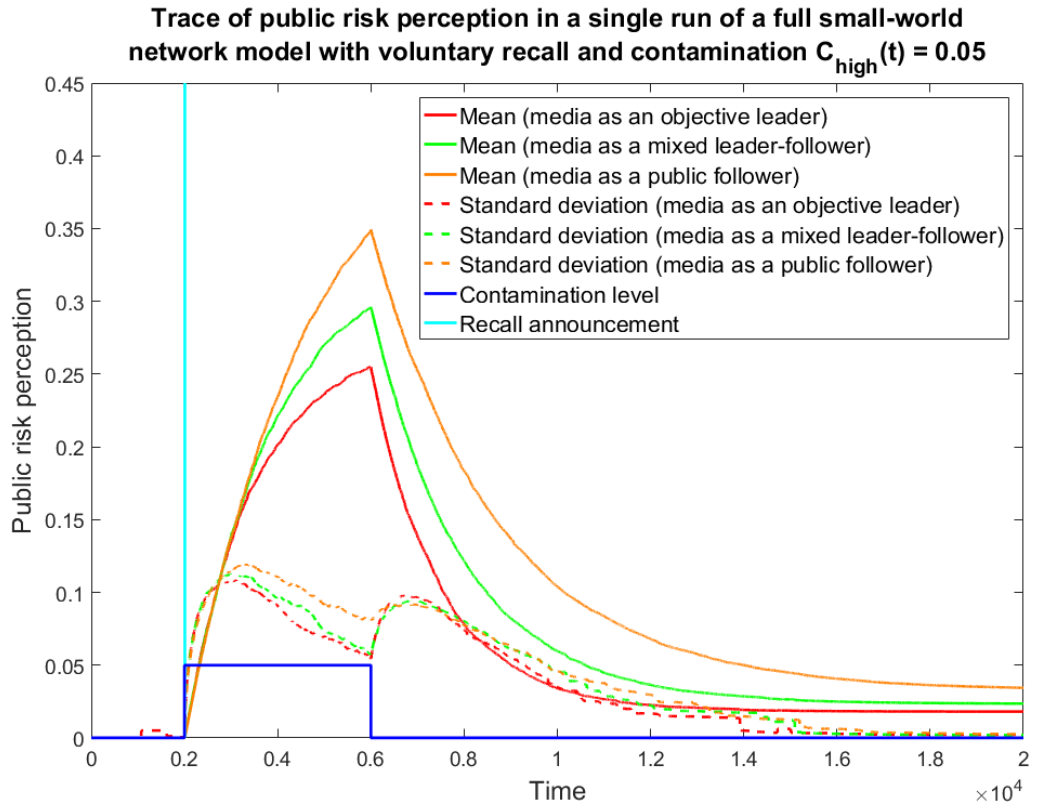
Figure 5.26 Trace of public risk perception in a single run of a full small-world network model with voluntary recall ( $a(t=2008)=1$, $v(t)=1$ ) and contamination $C_{high}(t)=0.05$
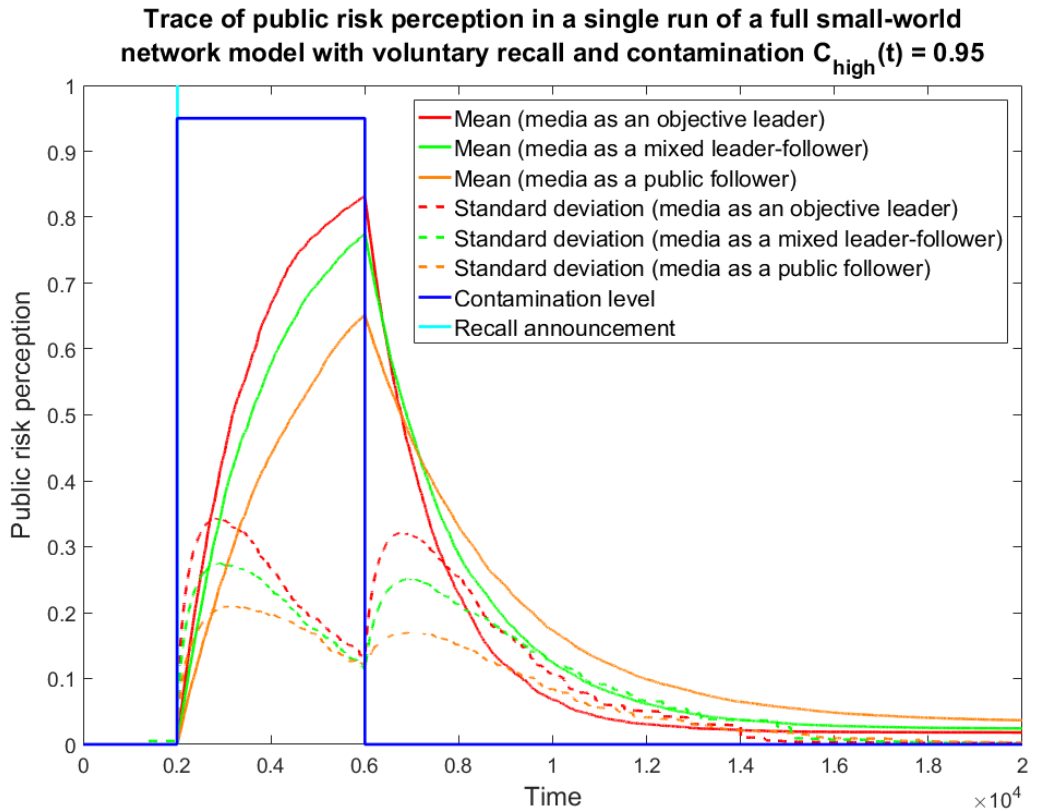


Figure 5.27 Trace of public risk perception in a single run of a full small-world network model with voluntary recall ( $a(t=2008)=1$, $v(t)=1$ ) and contamination $C_{high}(t)=0.95$

Figure 5.28 demonstrates that public risk perception is exaggerated to a higher degree during and after the crisis in the context of involuntary recall irrespective of the role of media (equation (5.10) with $v(t)=0$). Particularly, given the difference between these traces and those shown in Figure 5.24, media reporting appears to moderately alleviate the negative impact of an involuntary recall on public risk perception. Figure 5.29 and Figure 5.30 show an inverse relationship between risk amplification and contamination level.

Interestingly, the transition from a perfect mixing model to a small-world social network makes relatively little difference. It makes no difference qualitatively to the shape of the risk response, and only a small quantitative difference to the degree of the response. In the next chapter, where an attempt is made to calibrate the model from a survey of a real population, the difference made by the calibration step is also examined.
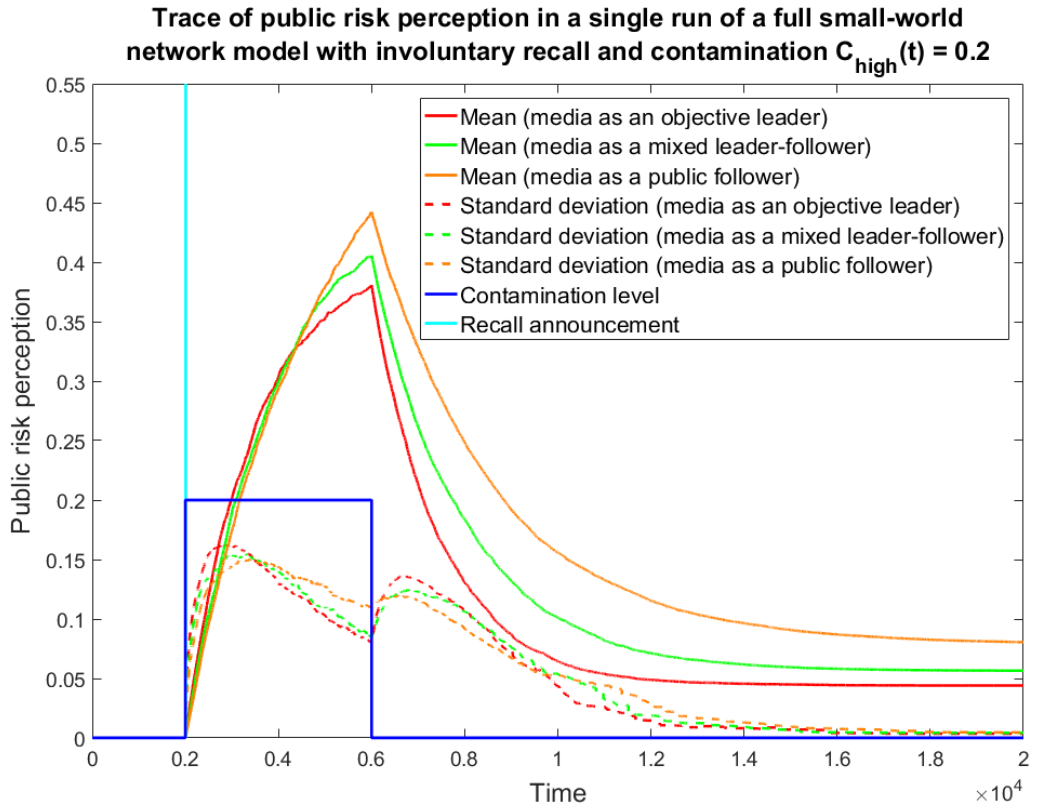


Figure 5.28 Trace of public risk perception in a single run of a full small-world network model with involuntary recall ($a(t=2003)=1$, $v(t)=0$) and contamination $C_{high}(t)=0.2$
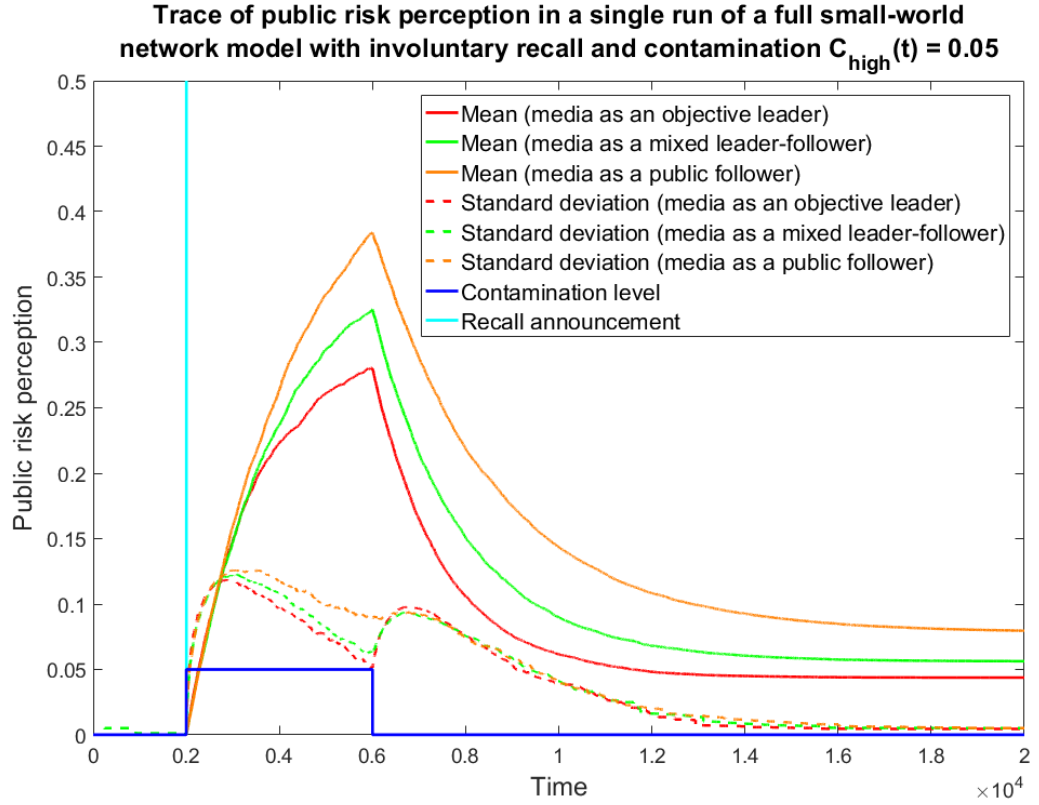
Figure 5.29 Trace of public risk perception in a single run of a full small-world network model with involuntary recall ( $a(t=2003)=1$ , $v(t)=0$ ) and contamination $C_{high}(t)=0.05$
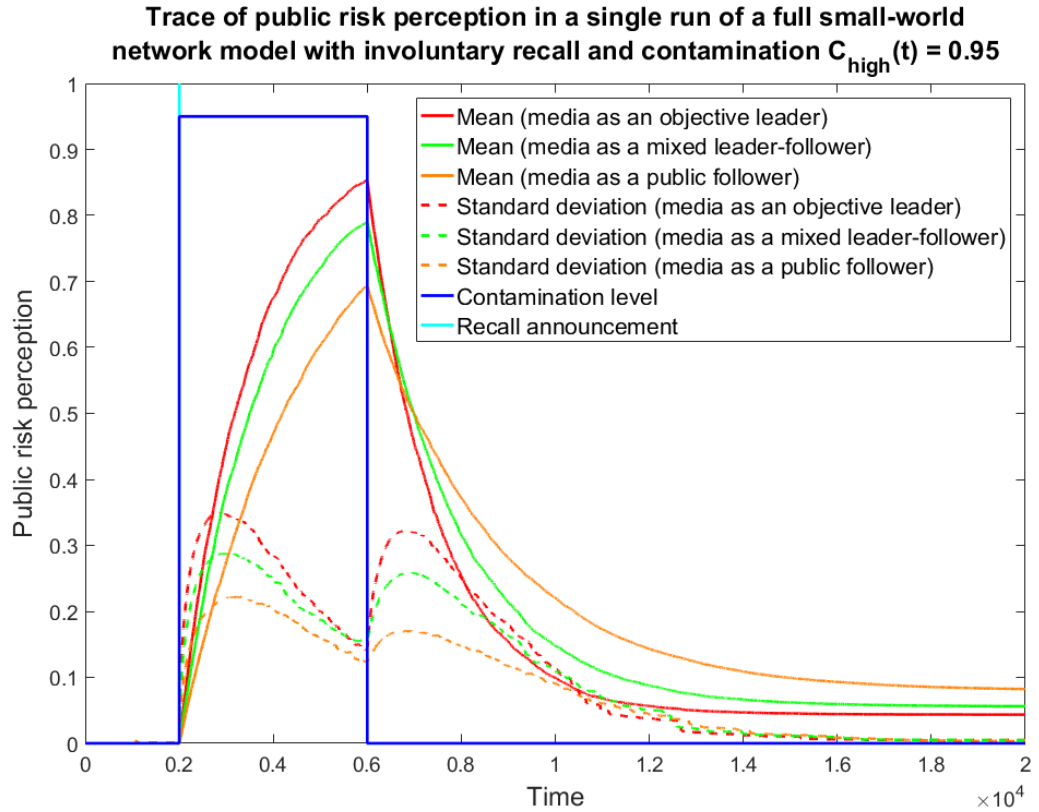
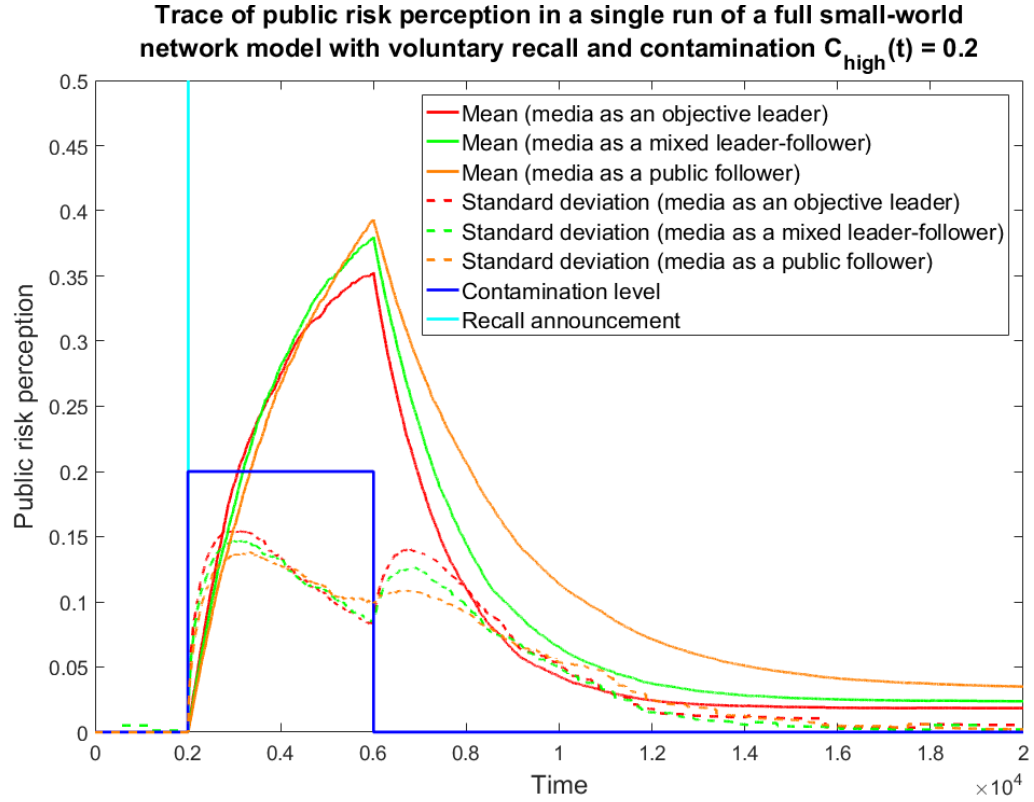

Figure 5.30 Trace of public risk perception in a single run of a full small-world network model with involuntary recall ( $a(t=2003)=1$ , $v(t)=0$ ) and contamination $C_{high}(t)=0.95$

# 6 CALIBRATING SURVEY

This chapter concerns calibrating the agent model using a consumer survey and the outcome the resulting model produces. It includes eight sections. The first section explains the aims of the survey – related to the micro-validity of the model. The second section describes design of the survey including the context in which the survey is conducted and structure of the survey. Sampling method and administration of the survey are dealt with in the third section, followed by a brief description of pilot test of the questionnaire in the fourth section. The fifth section describes characteristics of survey respondents. The sixth section presents survey results in terms of information sources and relative importance. The process of calibrating the model through the survey is depicted in the seventh section. Results of simulating the calibrated model follow.

## 6.1 Aims of the survey

The aim of the survey is to provide a certain level of calibration for the agent-based model. It performs part of what is often referred to as 'micro-validation' (Moss and Edmonds, 2005) by ensuring elements in the model correspond to empirically determined values. For this model, the micro-validation has two main elements: 1) assessing the information sources that people consult when forming risk perceptions; 2) assessing the relative importance they give to these sources in their decision rules. This produces empirical distributions over the weights people attach to the different sources, from which the parameters in the decision rules shown in Section 5.2.1 can be sampled in the agent model.

The uncalibrated model in Chapter 5 was based on assigning arbitrary weights to all sources for all agents. Within the risk discovery component of the model, these weights were simply made equal. The calibrating survey allows us to sample weights given to the different sources from a distribution of weights collected from a real sample of people making judgments about a particular situation.

## 6.2 Design of the survey

### 6.2.1 Context

As discussed in Chapter 3, the Sanlu milk scandal evolved into a nationwide dairy industry crisis and has been China's biggest food crisis struck to date. The incident caused several babies' death and ended up with thousands of babies being hospitalized. Chen (2009) argued

that the Sanlu milk powder scandal fell into one type of systemic risks, which, as Hennessy et al. (2003) have suggested, refers to "the risk that a system fails to perform because of the ways in which its various components interact". Asymmetric information and delayed risk communication among various social actors (e.g. consumers, mass media, Sanlu Group, the government, etc.) led to coordination failure (Chen, 2009), which is a marked feature of the case. When the recall of Sanlu milk powder in question was released, a great number of consumers had been experiencing panic and anger.

To some degree, the Sanlu milk scandal provides an ideal context for exploring the mechanism of social risk amplification and for identifying the role of various social interactions in the amplification process. However, as it is a powdered milk product, it will only be consumed by parents of newborns. The contaminant in Sanlu case was melamine (a type of plastics), but other milk contamination crises in China have been associated with biological agents. Therefore, the context for the survey is liquid milk product. And the contaminant is a biological agent, reflecting the most recent case (the Fonterra case).

## 6.2.2 Structure

The approach used in the survey is to ask participants to indicate what sources of information they will consult when facing an unexpected shock and to evaluate the relative influence among each possible pair of information sources. The survey is structured as shown below in Table 6.1. As mentioned earlier, liquid milk is the product involved in the contamination crisis. A fictitious company that carries out a product recall is created. A hypothetical brand name (i.e. ABC) is given to the company in order to avoid any brand-specific knowledge of participants that may distort their responses to survey questions.

The questions are divided into three sections – the first finding out the demographic profile of the respondents, the second dealing with which other agents the respondents expect to get information from, the third looking at the relative importance of the different types of source (the survey is displayed in Appendix B). For the convenience of quantitative model calibration, all comparisons are made relative to the same baseline, i.e. social interaction, except for the comparison between recall timing and recall voluntariness (which is used to assess the effects of recall timing and voluntariness on recreancy). For each pair of comparison, both forward comparison (e.g. when you form your risk perception, how much relative importance would you give to media communicated risk compared with other people's perceptions?) and reverse comparison (e.g. when you form your risk perception, how much relative importance would you give to other people's perceptions compared with media communicated risk?) are considered and randomly presented in the questionnaire in order to reduce cognitive biases that potential respondents may have. Presentation of questionnaire

items is also random within Section 3.

Table 6.1 Structure of survey

| Section 1<br>*Demographics* | Section 2<br>*Information sources* | Section 3<br>*Relative importance* |
|---|---|---|
| Gender | Friends<br>Colleagues<br>Neighbours<br>Family members<br>Other individuals in<br>your community<br>News media<br>Other | Own perception vs. other people's perceptions |
| Age | | Noticing contamination vs. other people's perceptions |
| Education | | Recall notice vs. other people's perceptions |
| Household income | | Recall timing vs. recall voluntariness |
| Having children | | Trust in the producer vs. other people's perceptions |
| | | Media communicated risk vs. other people's perceptions |

There is a specific mapping between individual questionnaire items and weights in the agent decision rules. Figure 6.1 shows this mapping between questionnaire items $Q_7$ to $Q_{12}$ and the main elements of the conceptual model. Specifically, information sources including own perception, other people's perceptions, noticing contamination, and product recall notice correspond to elements within the 'event discovery' component. Media communicated risk indicates the 'media' component, and feeling of trust indicates the 'recreancy' component in the model. In Section 3 of the survey, each questionnaire item represents a comparison between one information source and other people's perceptions, with the exception of $Q_{10}$, which compares recall timing with voluntariness.
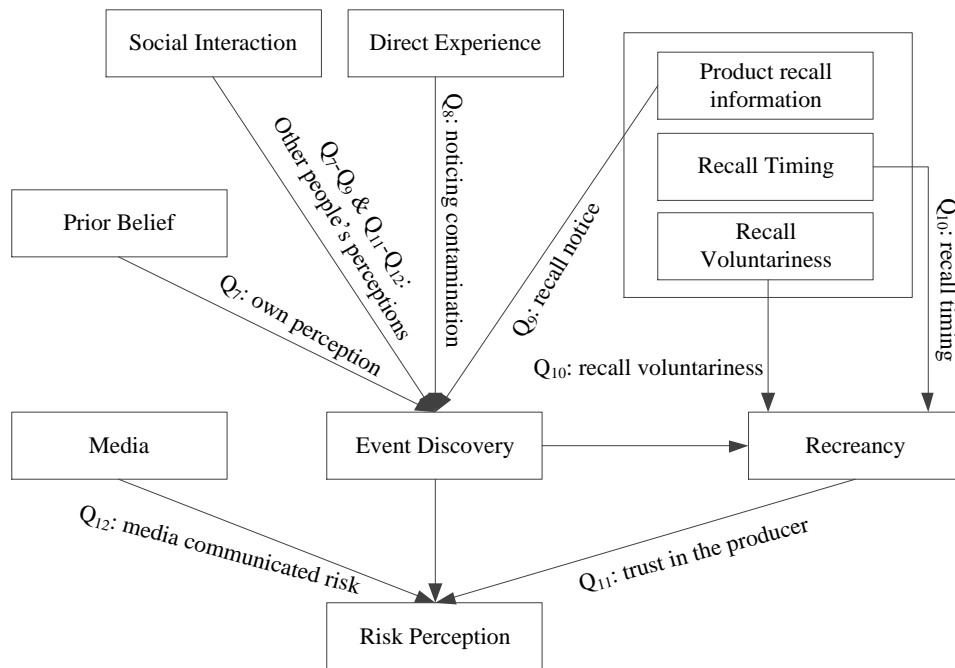
Figure 6.1 Mapping between questionnaire items and model elements

# 6.3 Sampling and administration

The survey used a convenience sampling approach as the aim was to demonstrate the general approach, not model a specific population responding to a specific product crisis. But it was conducted in China, as product contamination crises have been particularly prominent as risk events in China – for example the contaminated milk scandals.

The survey questionnaire was translated into Chinese before distribution. It was administered via an online survey platform - Qualtrics. And the survey link was posted onto community websites (i.e. Guokr.com and Douban.com), academic forums (i.e. muchong.com and bbs.pinggu.org), and a social media application (i.e. WeChat) to collect responses. There was an incentive of 10 forum coins (a normal, small payment for this kind of survey) for respondents on the forums, but no incentive was offered to those on the community websites and the social media application. The demographics of the sample are presented in Section 6.5. Of the 321 responses, 3 were from the community websites and 19 from the social media application and were therefore not remunerated.

The survey allowed respondents to progress to the next question without answering the present one. This was to collect as many responses to each question as possible without irritating respondents and without violating research ethics that apply to this study. There were 280 complete responses and 41 incomplete responses.

The survey was fully approved under the University's ethics system.

## 6.4 Pilot

The questionnaire was pre-tested to ensure validity of the content, correctness of the translation, understandability of the questionnaire items, and a reasonable amount of time taken to complete the questionnaire. The pilot test was not only an important step of finalizing the survey but also provided preliminary results regarding the types of information source people would like to turn to and the relative importance they give to the sources.

During the pilot 41 complete responses were received. These were collected by posting the pilot questionnaire online, and then asking friends to complete the survey, and ask their own friends to do the same. It took these participants between 2 and 7 minutes to complete the survey based on their own estimates of duration. Feedback from the participants suggested that the questionnaire was basically readable and understandable. But some people appeared to ignore the context of the questionnaire when responding to questions on relative importance of information sources, so minor changes were made to the layout of the questionnaire to improve its clarity. Results from the pilot showed that over 85% of respondents were willing to obtain risk information from news media, and that around 60% would consult their friends. With respect to relative importance, respondents attached more weight to their own beliefs, noticing contamination, recall notice, media communicated risk than others' perceptions, and they gave a bit greater importance to others' perceptions than trust in the producer. For respondents recall timing was more important than voluntariness.

## 6.5 Sample characteristics

The purpose of this section is to assess the appropriateness of the sample in the context of a product recall crisis in China. Overall, 321 responses including 280 complete ones were received. Approximately 12% of responses were from muchong.com, 6% from WeChat, 81% from bbs.pinggu.org, and Guokr.com and Douban.com only provided 1 and 2 responses, respectively. Demographic details of the survey respondents are presented in Table 6.2. Slightly more men responded (54.21%) than women (45.79%). The average respondent was 26.5 years old, with 73.52% of respondents aged between 21 and 30. 89.72% of respondents held at least a bachelor's degree. Mean household income before taxes was around £11,760. Only 13.71% of respondents were parents.

Table 6.2 Demographic details of survey respondents

| Item | Measure | Number (proportion) |
|---|---|---|
| Gender | Male | 174(54.21%) |
| | Female | 147(45.79%) |
| Age | 20 or less | 31(9.66%) |
| | 21 - 30 | 236(73.52%) |
| | 31 - 40 | 41(12.77%) |
| | 41 - 50 | 10(3.12%) |
| | 50 or more | 3(0.93%) |
| Education | Grade school | 11(3.43%) |
| | High school | 12(3.74%) |
| | Associate degree | 10(3.11%) |
| | Bachelor's degree | 141(43.93%) |
| | Master's degree or higher | 147(45.79%) |
| Household income | Less than £5,225 | 75(23.36%) |
| | £5,225 - £10,450 | 89(27.73%) |
| | £10,450 - £15,675 | 72(22.43%) |
| | £15,675 - £20,900 | 40(12.46%) |
| | £20,900 - £26,125 | 16(4.98%) |
| | £26,125 or more | 29(9.03%) |
| Having children | Yes | 44(13.71%) |
| | No | 277(86.29%) |

Sum-up data of the 2010 population census of China (i.e. the 6th population census of China) are provided in Table 6.3. Male and female population account for 51.19% and 48.81% of the entire population, separately. The proportions of male and female population are quite close to those of the survey sample, indicating that the survey sample largely reflects the population structure in terms of gender. But 17.14% of the population age lies between 20 and 29, while 73.52% of respondents fell within this range. Comparison regarding education between the census data and demographics of the survey sample reveals that survey respondents were more educated than residents in the country as a whole. Specifically, 89.72% of survey respondents had at least a bachelor's degree compared to 4% among the total population. In addition, there is obviously a higher fertility rate (23.62%) within the population than was the case for survey respondents (13.71%).

Table 6.3 2010 population census of China

| Item | Measure | Number (proportion) |
|---|---|---|
| Gender | Male | 682,329,104 (51.19%) |
| | Female | 650,481,765 (48.81%) |
| Age | 0 - 9 | 146,414,159 (10.97%) |
| | 10 - 19 | 174,797,576 (13.11%) |
| | 20 - 29 | 228,426,370 (17.14%) |
| | 30 - 39 | 215,164,162 (16.15%) |

| | 40 - 49 | 230,348,517 (17.38%) |
|---|---|---|
| | 50 - 59 | 160,065,645 (12.01%) |
| | 60 - 69 | 99,780,564 (7.48%) |
| | 70 - 79 | 56,824,530 (4.26%) |
| | 80 - 89 | 19,005,126 (1.42%) |
| | 90 - 99 | 1,948,286 (0.15%) |
| | 100 or more | 35,934 (0.0027%) |
| Education | None | 62,136,405 (5.00%) |
| | Grade school | 357,211,733 (28.75%) |
| | Junior high school | 518,176,222 (41.70%) |
| | Senior high school | 186,646,865 (15.02%) |
| | Junior college | 68,610,519 (5.52%) |
| | Bachelor's degree | 45,625,793 (3.67%) |
| | Master's degree or higher | 4,138,585 (0.33%) |
| Age-specific fertility rate | 15 - 19 | 5.93‰ |
| | 20 - 24 | 69.47‰ |
| | 25 - 29 | 84.08‰ |
| | 30 - 34 | 45.84‰ |
| | 35 - 39 | 18.71‰ |
| | 40 - 44 | 7.51‰ |
| | 45 - 49 | 4.68‰ |

Table 6.4 shows China's annual per capita income derived from the 2016 China Statistical Yearbook and family size from the 2010 population census of China. As data on annual household income of the Chinese population is unavailable, annual household income £7,524.6 was obtained by multiplying annual per capita income £2,508.2 by mean family size 3. Compared with the general population, the survey sample appeared to have a higher level of annual household income.

Table 6.4 2014 Annual per capita income and family size of China

| Item | Measure | Number (proportion) |
|---|---|---|
| Annual per capita income | Disposable personal income | £2,508.2 |
| Family size | 1-member family | 58,396,327 (14.53%) |
| | 2-member family | 97,947,686 (24.37%) |
| | 3-member family | 107,978,654 (26.86%) |
| | 4-member family | 70,598,493 (17.56%) |
| | 5-member family | 40,332,512 (10.03%) |
| | 6-member family | 16,887,554 (4.20%) |
| | 7-member family | 5,753,970 (1.43%) |
| | 8-member family | 2,235,271 (0.56%) |
| | 9-member family | 942,511 (0.23%) |
| | 10-member family or more | 861,218 (0.21%) |

In general, the demographic characteristics of the survey respondents were consistent with the China census data in terms of gender but differed in aspects of age, education, household

income, and fertility rate. The responses were mainly collected from community websites and academic forums that are popular for young and educated people, resulting in the fact that older and non-educated people are less likely to be included in the sample. This is an important qualification to bear in mind. The survey data are still used to calibrate the model, but this means that the model is a model of how young, well-educated people respond to a crisis of this kind – not a model of how the Chinese population as a whole would respond.

## 6.6 Survey results

### 6.6.1 Information sources

The data on information sources show that 89.7% of the survey respondents would consult news media when forming risk beliefs, and that 56.4% would refer to friends' opinions. Family members, as shown in Figure 6.2, is the third most popular source of information people would like to take advantage of. The results manifest the importance of social interaction and media in shaping responses to risk associated with a milk contamination crisis in China and justify the incorporation of these two elements in the model. In addition, respondents indicated a fixed number of individuals they would communicate with and a specific number of media outlets they would consult. However, the numbers are not used for calibration, because the number of neighbours each agent interacts with is a global parameter that cannot be calibrated and only a single media agent is considered in order to keep the model simple.
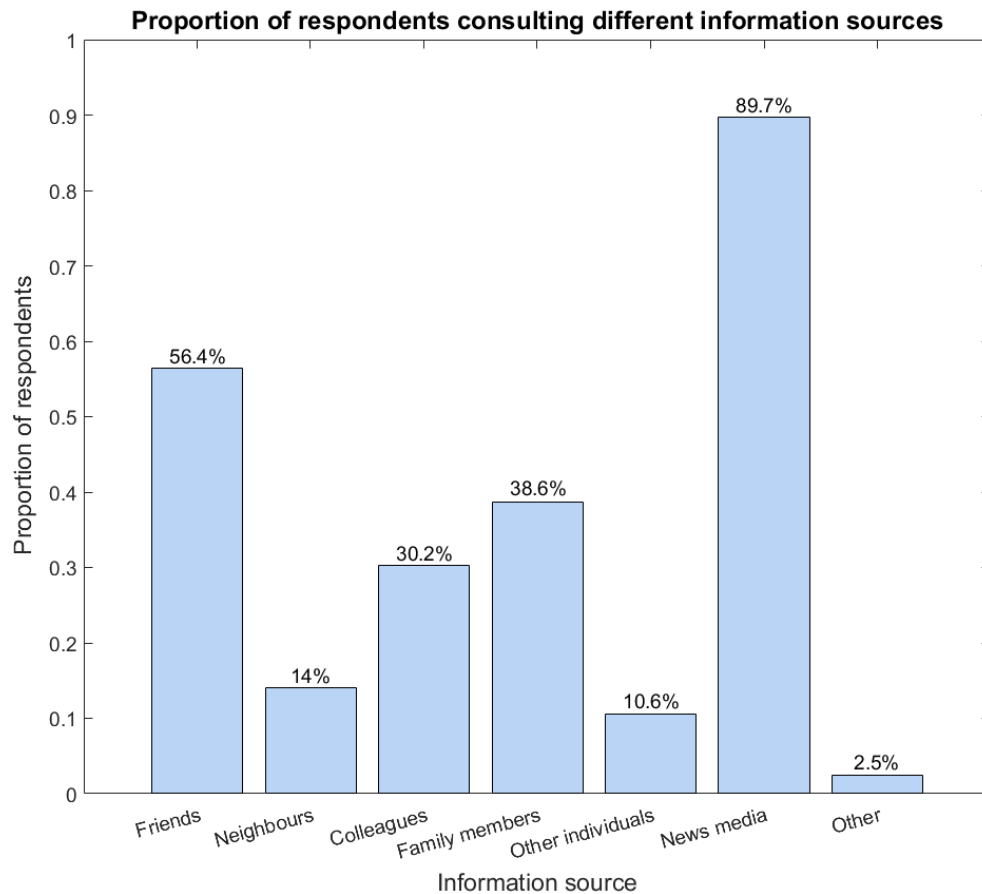
Figure 6.2 Proportion of respondents consulting different information sources

## 6.6.2 Relative importance

In the survey questionnaire items within Section 3 are recoded as a numeric value that is automatically assigned to each answer choice in Qualtrics. Recoded values are assigned in the order the answer choices are created. By default, the first answer choice is coded as a 1, the second as a 2, and so forth. Table 6.5 presents the mapping between recoded value, answer choice, and ratio, for each of the questionnaire items. Ratio is calculated by dividing the relative importance of the first information source by the relative importance of the second one in each pair of comparison. Because the ratio corresponding to the recoded value 11 is infinity, a value 10 is chosen based on the subjective preference of the modeller.

Table 6.5 Mapping between recoded value, answer choice, and ratio

| Recoded value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Answer choice | 0, 100% | 10%, 90% | 20%, 80% | 30%, 70% | 40%, 60% | 50%, 50% | 60%, 40% | 70%, 30% | 80%, 20% | 90%, 10% | 100%, 0 |
| Ratio | 0 | 0.11 | 0.25 | 0.43 | 0.67 | 1 | 1.5 | 2.33 | 4 | 9 | 10 |

The recoded value of each answer choice in reverse comparison is first transformed to its recoded value in forward comparison according to the following relationship:

$$\mathrm{Re}\,coded\ value\big(forward\ comparison\big)=12-\mathrm{Re}\,coded\ value\big(reverse\ comparison\big) \qquad (6.1)$$

And then add up the frequencies of the same recoded value in both comparisons to obtain a combined frequency. Figures 6.3 to 6.8 show frequency distributions of questionnaire items with respect to relative importance of different pairs of information sources. It appears that respondents give less importance to other people's perceptions in all of the comparisons between two information sources, except for the comparison between trust in the producer and other people's perceptions. The low relative importance of trust largely coincides with Chinese people's attitude toward food crises. Food safety problems have occurred quite frequently in recent years in China, which results in a great loss of consumer confidence and trust in food manufacturers (Yan, 2012). Dishonesty and unreliability Chinese food companies exhibited in food crises have made it hard for consumers to believe in what involved companies say and do whenever there is a product harm crisis. The level of trust people invest in the producer is, therefore, not an important basis for estimating risks associated with a food contamination incident. Another observation is that respondents put a greater emphasis on recall timing than recall voluntariness. There were 280 complete responses for which the respondents have answers for every item. The following figures show for each item the total number for that item (which for some items exceeded 280).
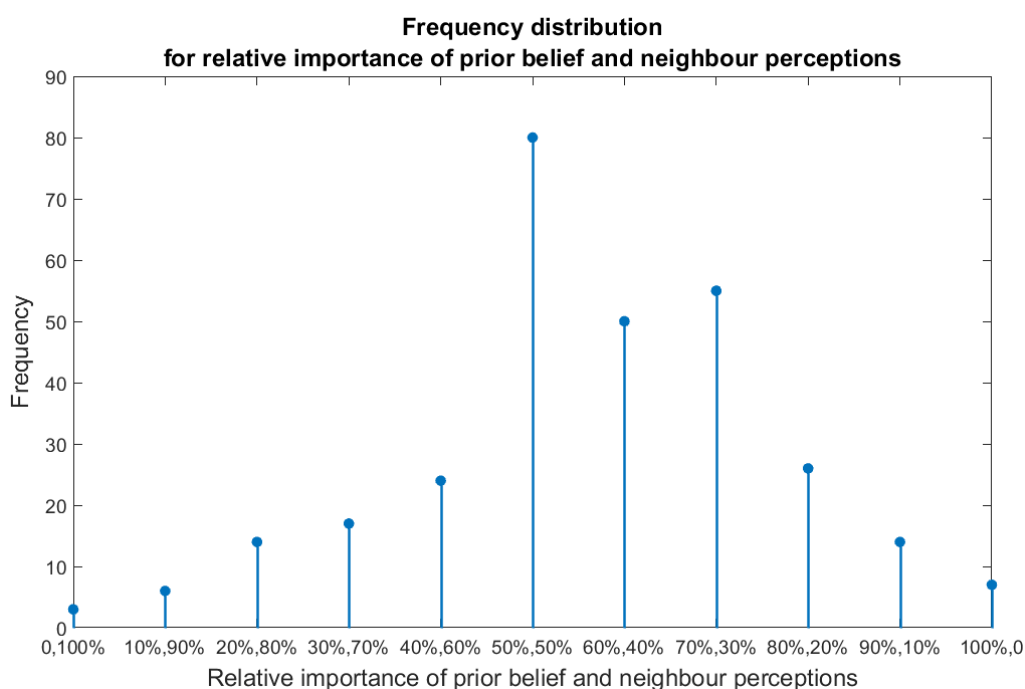


Figure 6.3 Frequency distribution for relative importance of prior belief and neighbour perceptions
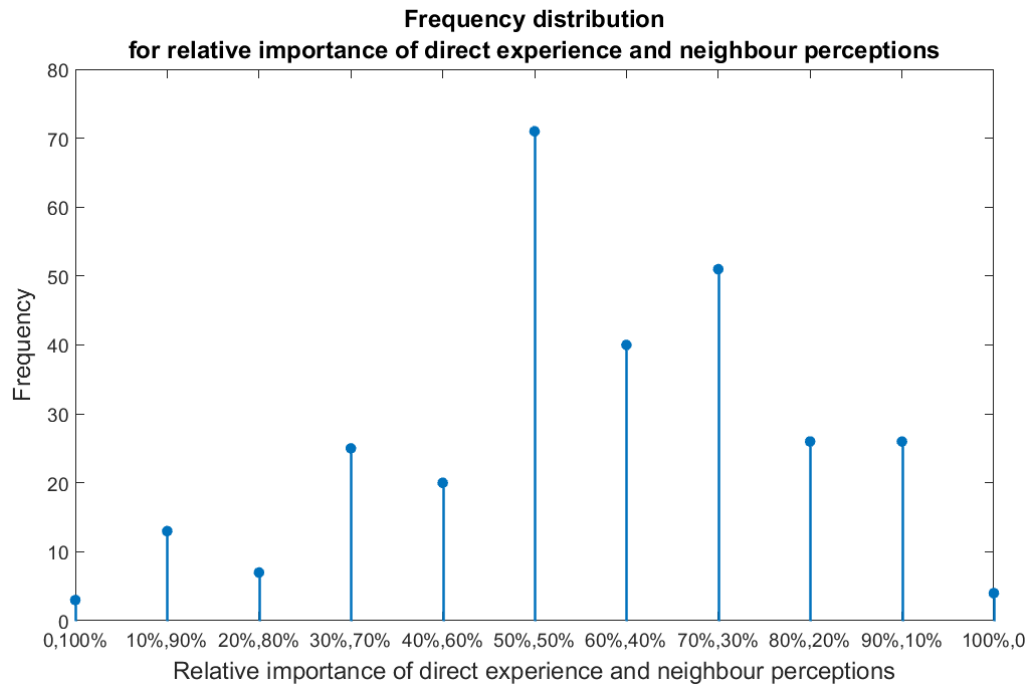
Figure 6.4 Frequency distribution for relative importance of direct experience and neighbour perceptions
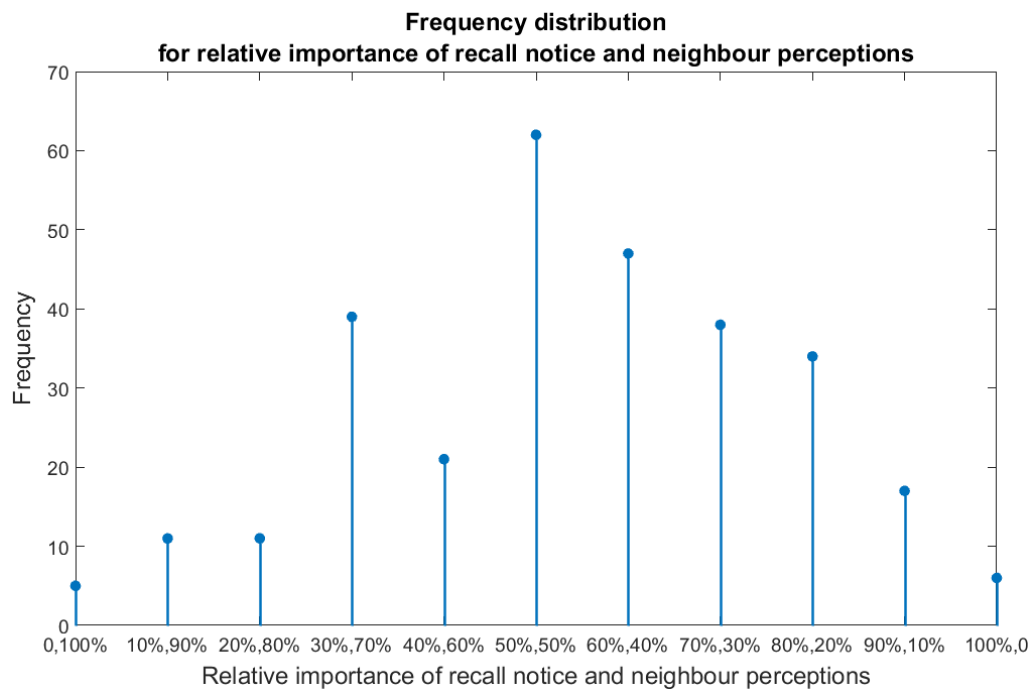


Figure 6.5 Frequency distribution for relative importance of recall notice and neighbour perceptions
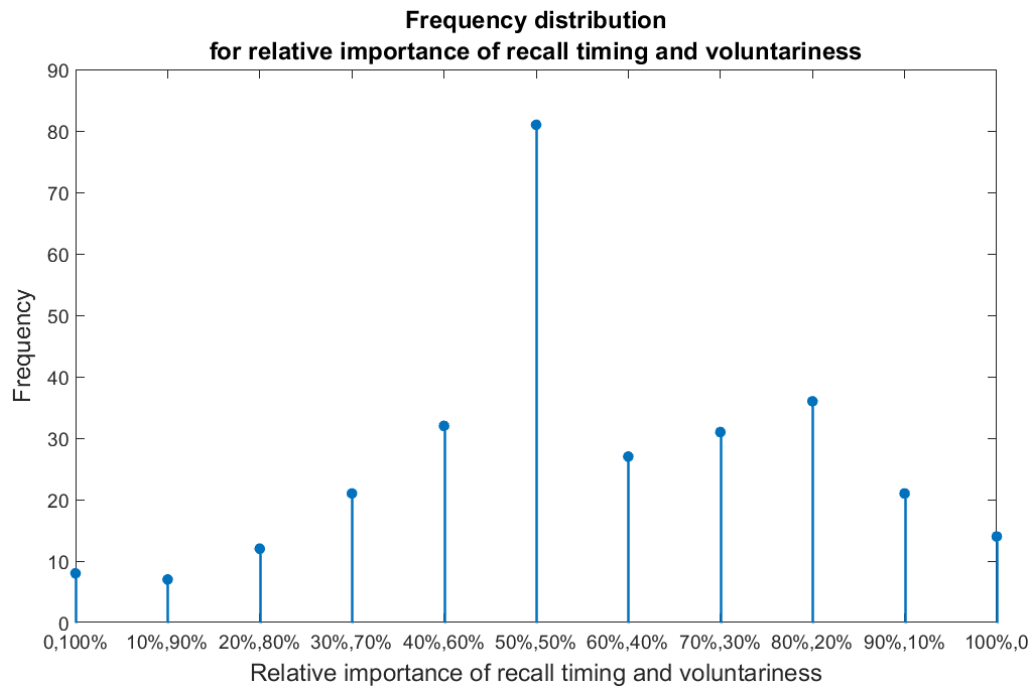
Figure 6.6 Frequency distribution for relative importance of recall timing and voluntariness
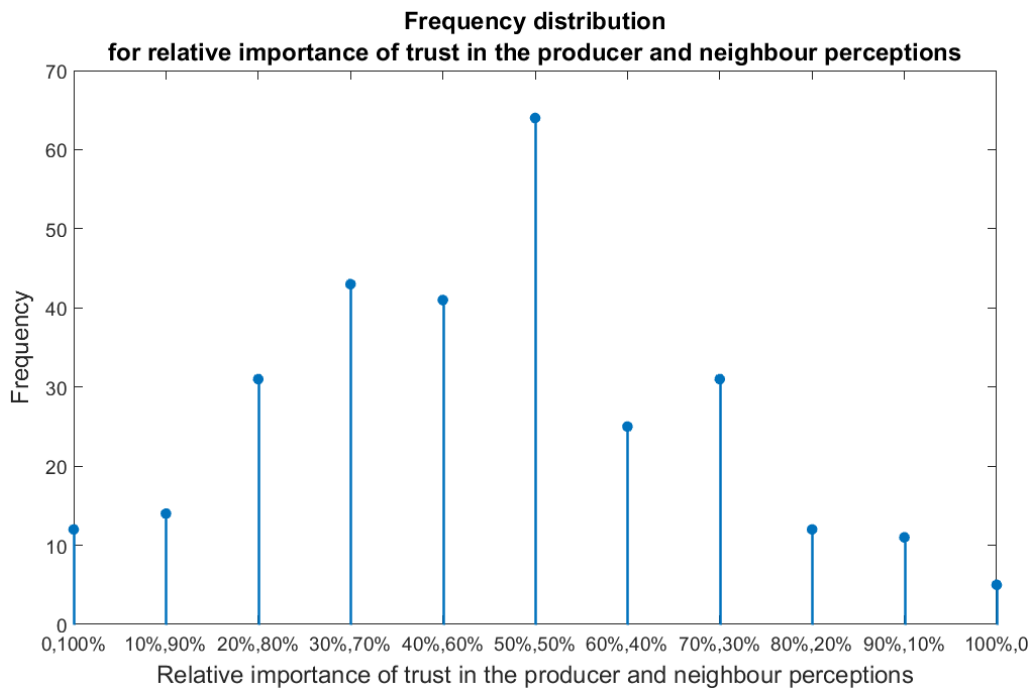


Figure 6.7 Frequency distribution for relative importance of trust in the producer and neighbour perceptions

**Frequency distribution
for relative importance of media communicated risk and neighbour perceptions**
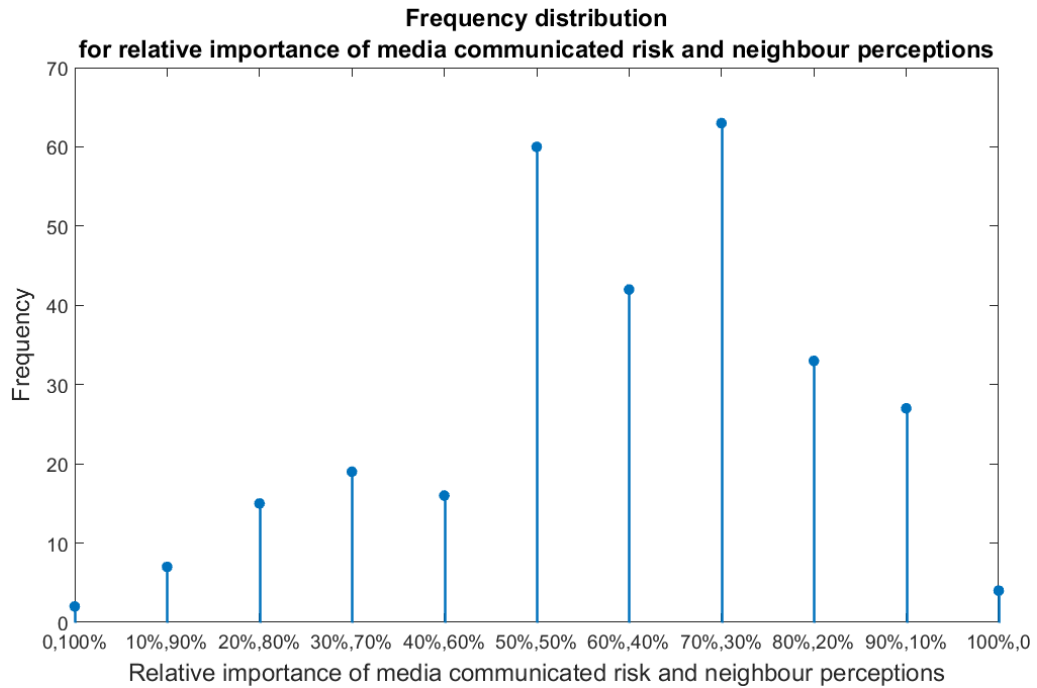
Figure 6.8 Frequency distribution for relative importance of media communicated risk and neighbour perceptions

Table 6.6 provides descriptive statistics of the frequency distributions of questionnaire items. $Q_7$, $Q_8$, $Q_9$, $Q_{10}$, $Q_{11}$, and $Q_{12}$ correspond to survey questions concerning relative importance of two different information sources and are used to represent relevant questionnaire items. Mode, mean, and variance are recorded as recoded values. The mode for all cases is 6 (i.e. 50% vs. 50%), with an exception of 8 (i.e. 70% vs. 30%) for the comparison between media communication and other people's perceptions. The mean is between 6 (which maps to ratio 1) and 7 (which maps to ratio 1.5) for all cases except questionnaire item $Q_{11}$ regarding the comparison between trust in the producer and others' perceptions (the mean is between 5 mapping to ratio 0.67 and 6 mapping to ratio 1). The frequency distribution of $Q_{11}$ is skewed to the right, while for the rest the distributions are left-skewed with negative skewness. This indicates that people value trust in the producer less than other sources of information. It means, as mentioned earlier, that in the context of a Chinese milk contamination crisis people do not rely on their feeling of trust in the company much in making a decision about the risk. In addition, of all the cases only the frequency distribution of questionnaire item $Q_7$ has a kurtosis greater than 3 (the kurtosis of a standard normal distribution is 3). That is to say, the distribution of $Q_7$ is heavy-tailed and has outliers. There is a slightly larger proportion of respondents who attach less or equal importance to other people's perceptions in the case of comparison between own perception and other people's perceptions than in other cases.

Table 6.6 Descriptive statistics of frequency distributions of questionnaire items

| Questionnaire item | Mode | Mean | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|
| $Q_7$ : own perception vs. other people's perceptions | 6 | 6.64 | 3.97 | -0.2875 | 3.1804 |
| $Q_8$ : noticing contamination vs. other people's perceptions | 6 | 6.65 | 4.70 | -0.3446 | 2.7996 |
| $Q_9$ : recall notice vs. other people's perceptions | 6 | 6.42 | 5.01 | -0.2170 | 2.5807 |
| $Q_{10}$ : recall timing vs. recall voluntariness | 6 | 6.60 | 5.51 | -0.1466 | 2.7050 |
| $Q_{11}$ : trust in the producer vs. other people's perceptions | 6 | 5.50 | 5.22 | 0.1730 | 2.6628 |
| $Q_{12}$ : media communicated risk vs. other people's perceptions | 8 | 6.90 | 4.46 | -0.4672 | 2.8010 |

Table 6.7 shows correlation coefficients between different questionnaire items. The correlations between different items are all weak. However, for a two-tailed test the correlations between $Q_7$ and $Q_8$ ( $p < 0.001$ ), between $Q_7$ and $Q_{12}$ ( $p < 0.001$ ), and between $Q_8$ and $Q_{12}$ ( $p = 0.003$ ) are significant at a 0.01 significance level, and there is a statistically significant linear relationship between $Q_7$ and $Q_{11}$ ( $p = 0.02$ ) with a significance level of 0.05. Therefore, it looks as though the respondents are making separate, individual decisions to develop risk judgments. And the different items do clearly ask about different constructs.

Table 6.7 Correlation coefficients between questionnaire items

| Questionnaire item | $Q_7$ | $Q_8$ | $Q_9$ | $Q_{10}$ | $Q_{11}$ | $Q_{12}$ |
|---|---|---|---|---|---|---|
| $Q_7$ | 1 | — | — | — | — | — |
| $Q_8$ | 0.2410** | 1 | — | — | — | — |
| $Q_9$ | 0.0766 | 0.1038 | 1 | — | — | — |
| $Q_{10}$ | -0.0328 | -0.0533 | -0.0907 | 1 | — | — |
| $Q_{11}$ | 0.1391* | 0.0336 | 0.1029 | -0.0285 | 1 | — |
| $Q_{12}$ | 0.2503** | 0.1767** | 0.0168 | 0.0323 | -0.0031 | 1 |

**. Correlation is significant at the 0.01 level (two-tailed).

*. Correlation is significant at the 0.05 level (two-tailed).

## 6.7 Model calibration

Chapter 5 shows the final decision rule for agents updating their risk beliefs without calibration weights. This rule is now updated with weights as follows. The symbols have the same meaning as in Section 5.2.1.

$$b_i(t) = w_1 \left( w_2 b_i(t-1) + w_3 \frac{1}{K} \sum_{nj=1}^{K} b_{nj}(t) + w_4 e_i(t) + w_5 r(t) \right) + w_6 R_i(t) + w_7 M(t) \quad (6.2)$$

where $w_1$, $w_6$, and $w_7$ are the weight given to 'event discovery', 'recreancy', and communication from 'media', $w_1 + w_6 + w_7 = 1$, $w_2$, $w_3$, $w_4$, and $w_5$ are the weight given to prior belief, social interaction, direct experience, and recall information within 'event discovery' component, and $w_2 + w_3 + w_4 + w_5 = 1$. As in the original uncalibrated model, the initial conditions are that all agents have a randomly endowed prior risk belief $b_i(t=0) \in [0, I]$ and randomly endowed recreancy judgment $R_i(t=0) \in [0, I]$. Also, the media belief $M(t)$ prior to the crisis is set at 0.

Pair consistency between forward comparison and reverse comparison is evaluated by comparing mean of mean of the two comparisons with the central recoded value 6, that is:

$Pair\ consistency = mean\big(mean\big(forward\ comparison\big) + mean\big(reverse\ comparison\big)\big) - 6$ (6.3)

Table 6.8 shows 1) the mean of forward comparisons and of reverse comparisons, 2) the consistency values between the forward and reverse comparisons, 3) the mapping between questionnaire items and parameterized weights. Obviously, there is a good consistency between forward comparison and reverse comparison in each case. This indicates little judgment bias from respondents that can possibly be caused by the way in which the questions are designed – most comparisons are made relative to the same baseline.

Table 6.8 Pair consistency and mapping between questionnaire items and parameterized weights

| Questionnaire item | Source A | Source B | Mean | Pair consistency | Parameterized weight |
|---|---|---|---|---|---|
| $Q_7$ | Own perception | Other people's perceptions | 6.67 | 0.03 | $w_2/w_3$ |
| | Other people's perceptions | Own perception | 5.39 | | |
| $Q_8$ | Noticing contamination | Other people's perceptions | 6.61 | -0.035 | $w_4/w_3$ |
| | Other people's perceptions | Noticing contamination | 5.32 | | |
| $Q_9$ | Recall notice | Other people's perceptions | 6.36 | -0.06 | $w_5/w_3$ |
| | Other people's perceptions | Recall notice | 5.52 | | |
| $Q_{10}$ | Recall timing | Recall voluntariness | 6.69 | 0.095 | $D/E$ |
| | Recall voluntariness | Recall timing | 5.50 | | |
| $Q_{11}$ | Trust in the producer | Other people's perceptions | 5.31 | -0.19 | $w_6/w_1 w_3$ |

| | Other people's perceptions | Trust in the producer | 6.31 | | |
|---|---|---|---|---|---|
| $Q_{12}$ | Media communicated risk | Other people's perceptions | 6.64 | -0.255 | $w_7/w_1 w_3$ |
| | Other people's perceptions | Media communicated risk | 4.85 | | |

The questionnaire items $Q_i (i = 7, 8, 9, 11, 12)$ do not indicate the weights directly. The weights have to be inferred from the $Q_i (i = 7, 8, 9, 11, 12)$ according to the following relationship:

$$w_1 = \frac{1 + Q_7 + Q_8 + Q_9}{1 + Q_7 + Q_8 + Q_9 + Q_{11} + Q_{12}}, \quad w_2 = \frac{Q_7}{1 + Q_7 + Q_8 + Q_9}, \quad w_3 = \frac{1}{1 + Q_7 + Q_8 + Q_9},$$

$$w_4 = \frac{Q_8}{1 + Q_7 + Q_8 + Q_9}, \quad w_5 = \frac{Q_9}{1 + Q_7 + Q_8 + Q_9}, \quad w_6 = \frac{Q_{11}}{1 + Q_7 + Q_8 + Q_9 + Q_{11} + Q_{12}},$$

$$w_7 = \frac{Q_{12}}{1 + Q_7 + Q_8 + Q_9 + Q_{11} + Q_{12}}.$$

where $w_1$, $w_2$, $w_3$, $w_4$, $w_5$, $w_6$, and $w_7$ are the weight given to event discovery, prior belief, social interaction, direct experience, product recall, recreancy, and media communication, and $Q_7$, $Q_8$, $Q_9$, $Q_{11}$, and $Q_{12}$ represent the questionnaire items for own perception vs. others' perceptions, noticing contamination vs. others' perceptions, recall notice vs. others' perceptions, trust in the producer vs. others' perceptions, and media communicated risk vs. others' perceptions, respectively.

Here is a numerical example of how the weights for each respondent were calculated based on data from the survey. Take respondent 2 for example, the respondent's answers for $Q_i (i = 7, 8, 9, 11, 12)$ were 60% vs. 40%, 80% vs. 20%, 70% vs. 30%, 10% vs. 90%, 20% vs. 80%, and 90% vs. 10%, so $Q_7 = 1.5$, $Q_8 = 4$, $Q_9 = 2.33$, $Q_{11} = 0.25$, and $Q_{12} = 9$ based on Table 6.5. Then the values of $Q_i (i = 7, 8, 9, 11, 12)$ were put into the equations shown above. The resulting weights for the respondent were:

$$w_1 = \frac{1 + 1.5 + 4 + 2.33}{1 + 1.5 + 4 + 2.33 + 0.25 + 9} = 0.4884, \quad w_2 = \frac{1.5}{1 + 1.5 + 4 + 2.33} = 0.1699,$$

$$w_3 = \frac{1}{1 + 1.5 + 4 + 2.33} = 0.1132, \quad w_4 = \frac{4}{1 + 1.5 + 4 + 2.33} = 0.453,$$

$$w_5 = \frac{2.33}{1 + 1.5 + 4 + 2.33} = 0.2639, \quad w_6 = \frac{0.25}{1 + 1.5 + 4 + 2.33 + 0.25 + 9} = 0.0138,$$

$$w_7 = \frac{9}{1 + 1.5 + 4 + 2.33 + 0.25 + 9} = 0.4978.$$

The dataset obtained for each weight is fitted with a beta distribution, and these are then used as sampling distributions for the agents in the model, such that all agents follow the same updating rule but each agent adopts a unique set of parameter values sampled from these distributions. Beta distributions are used because they have a bounded support. This assumes the scale underlying the discrete response items in the questionnaire is continuous, and then the weights are continuous as well. With two positive shape parameters, beta distribution visually looks as though it could produce a sound fit to the data concerning the weights in the model. Table 6.9 provides the mean, variance, and shape parameters for each information source in the model.

Table 6.9 Mean, variance, and shape parameters for information sources in the model

| Information source | Parameterized weight | Mean | Variance | Shape parameters |
|---|---|---|---|---|
| Event discovery | $w_1$ | 0.6668 | 0.0263 | 4.9717, 2.4845 |
| Prior belief | $w_2$ | 0.2713 | 0.0252 | 1.8584, 4.9923 |
| Social interaction | $w_3$ | 0.1867 | 0.0110 | 2.3813, 10.3749 |
| Direct experience | $w_4$ | 0.2806 | 0.0312 | 1.5325, 3.9291 |
| Product recall information | $w_5$ | 0.2615 | 0.0300 | 1.4213, 4.0147 |
| Recreancy | $w_6$ | 0.1262 | 0.0146 | 0.8285, 5.7348 |
| Media communication | $w_7$ | 0.2070 | 0.0214 | 1.3814, 5.2928 |

The following figures, Figures 6.9 to 6.15, show for each weight the frequency distribution based on the questionnaire responses and the probability density function that has been fitted. The probability density function was done by using the $betapdf\left(W, SP1, SP2\right)$ function in MATLAB, where $W$ represents an array of weights of an information source, and $SP1$ and $SP2$ are shape parameters of the beta distribution of this information source. In general, a beta distribution appears suited to the weights of most elements in the model. Following the figures, the goodness of fit indexes will be presented.
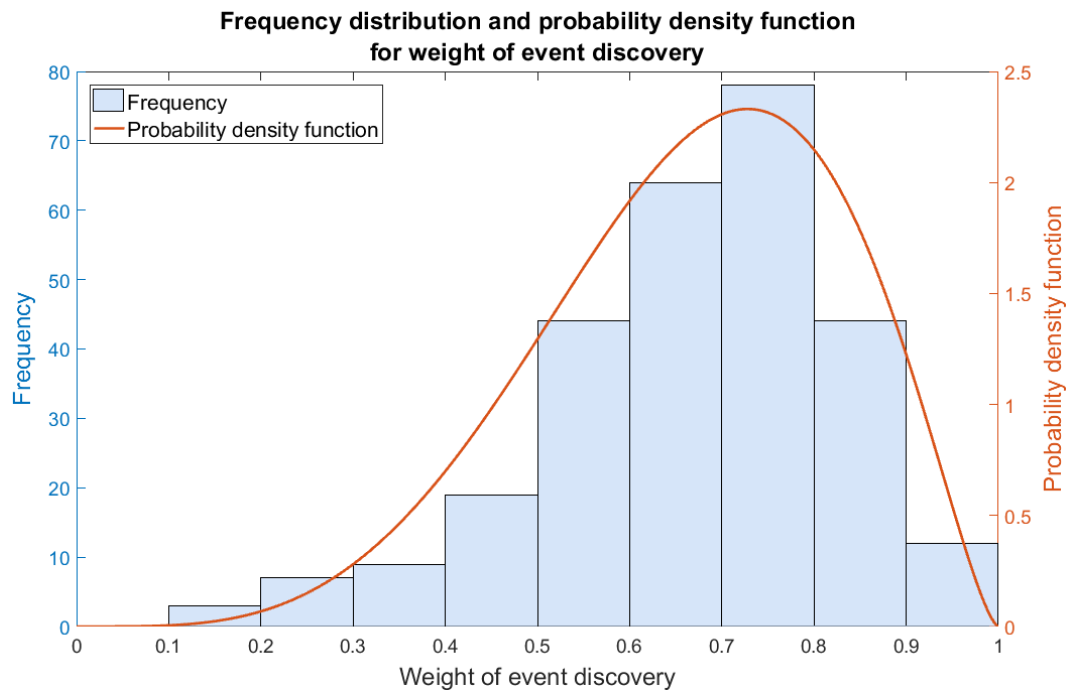
Figure 6.9 Frequency distribution and probability density function for weight of event discovery
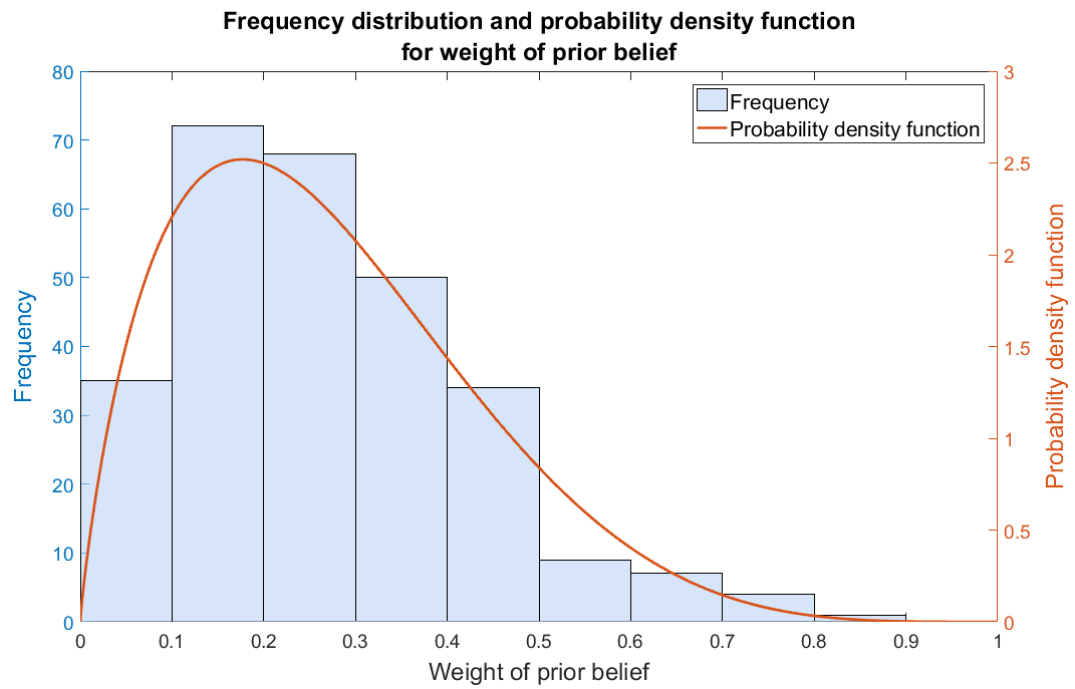


Figure 6.10 Frequency distribution and probability density function for weight of prior belief
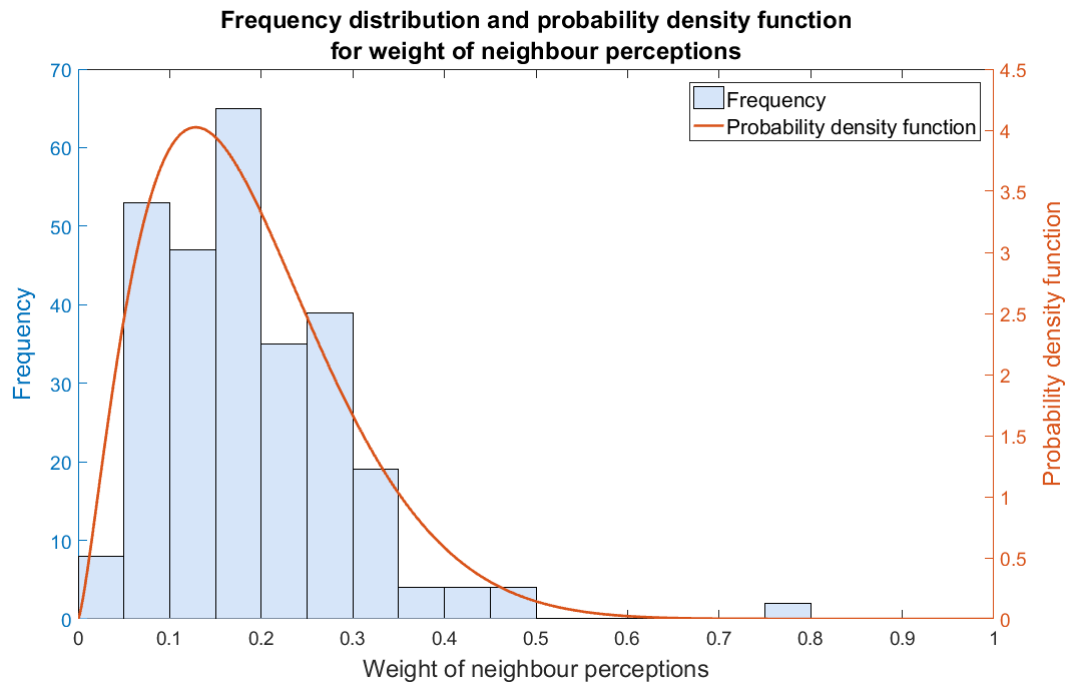
Figure 6.11 Frequency distribution and probability density function for weight of neighbour perceptions
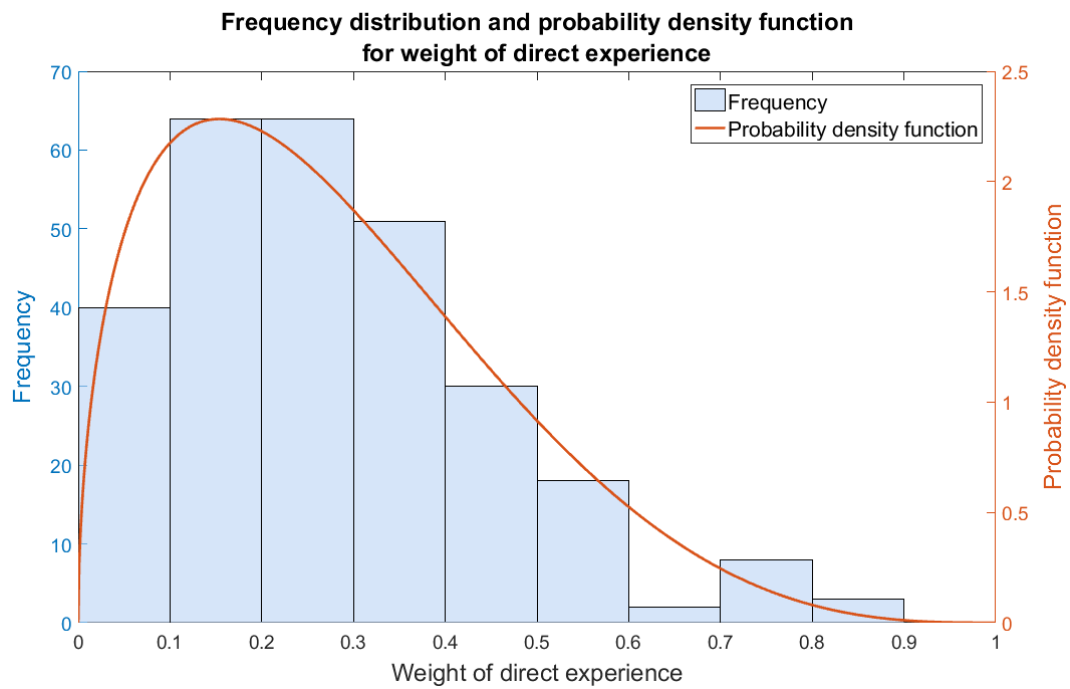


Figure 6.12 Frequency distribution and probability density function for weight of direct experience
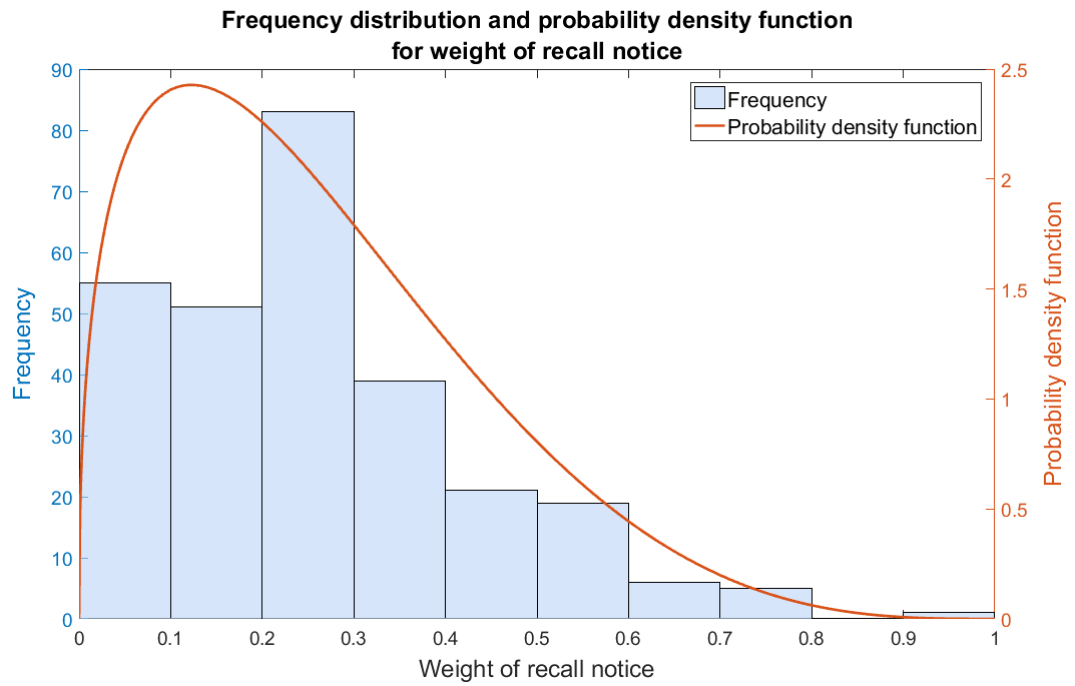
Figure 6.13 Frequency distribution and probability density function for weight of recall notice
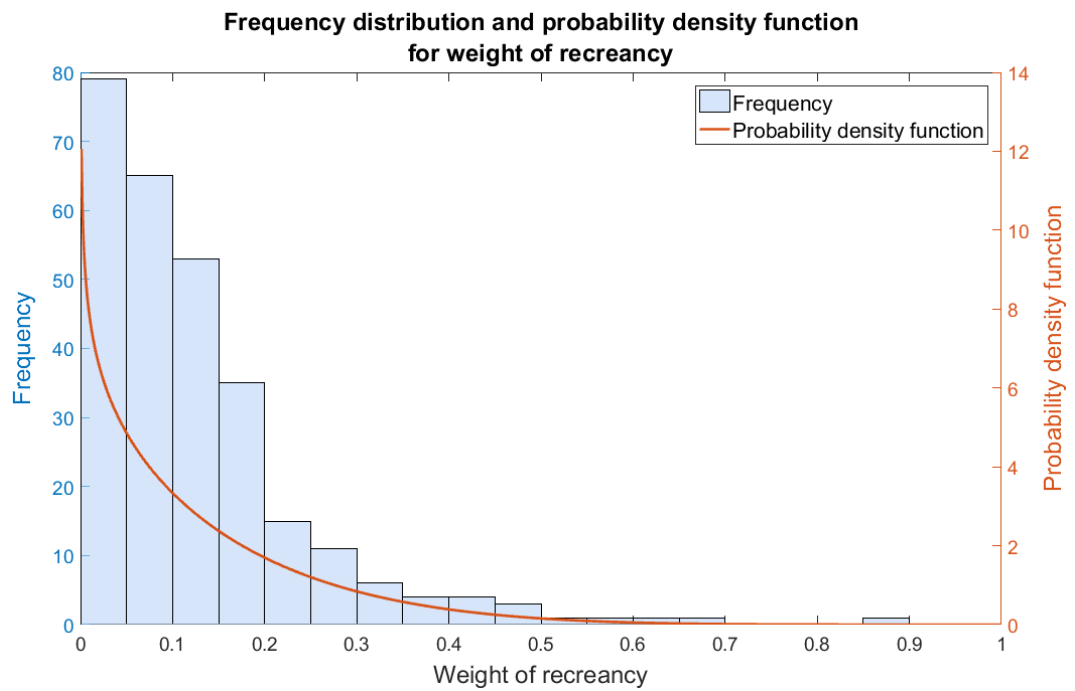


Figure 6.14 Frequency distribution and probability density function for weight of recreancy
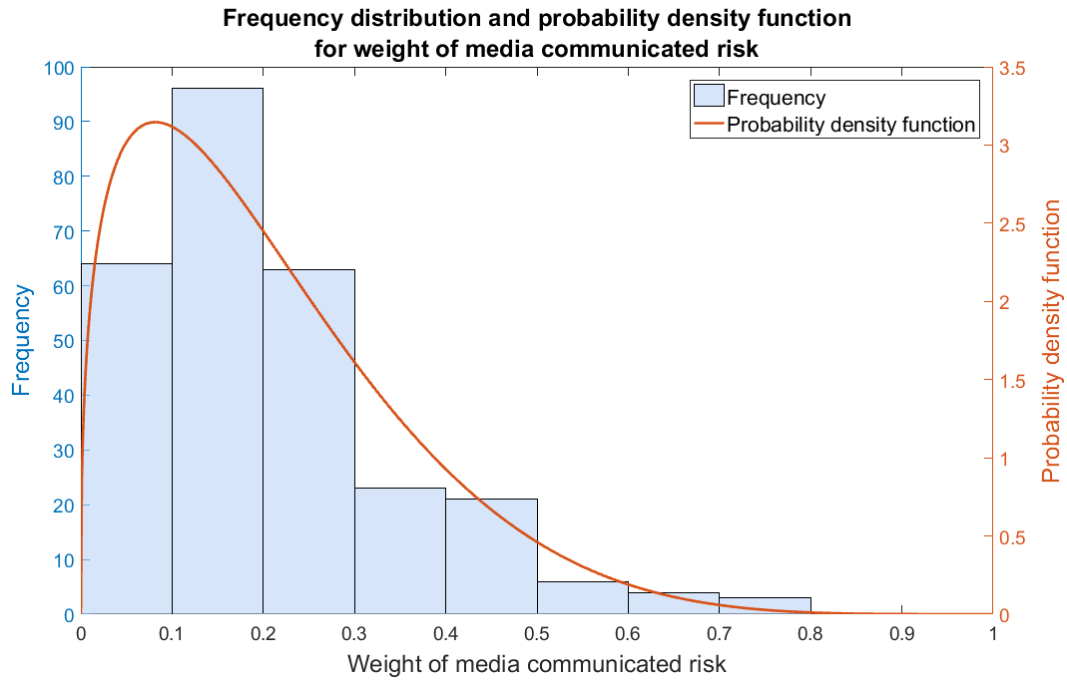
Figure 6.15 Frequency distribution and probability density function for weight of media communicated risk

The goodness of fit is evaluated using one-sample Kolmogorov-Smirnov test, which is a nonparametric test of the null hypothesis that the data conform to a specified distribution. Table 6.10 provides the test statistic $k$ and $p$-value. The $p$-value is very dependent on the sample size, and until now no particular value has been found most desirable (Dorey, 2010; Hooper, 2011; Poole, 2001). Thus in this case $p$-value needs to be as high as possible to claim that the samples are drawn from a beta distribution. As shown in Table 6.10, recreancy has a smallest $p$-value and accordingly a largest test statistic $k$ in all cases. The fit for recreancy (Figure 6.14) clearly looks quite a poor fit, probably because the mode lies at the lowest interval of $[0,1]$ and the frequencies all fall within the left side of the interval. Because in equation (6.2) $w_1 + w_6 + w_7 = 1$ (where $w_1$, $w_6$, and $w_7$ are the weight of 'event discovery', 'recreancy', and perception expressed in the 'media'), the weight of recreancy $w_6$ is not sampled from the distribution but equal to $1 - w_1 - w_7$. Similarly, of the four information sources that contribute to risk discovery, the weight of product recall information $w_5$ exhibits a relatively small $p$-value and is therefore calculated as $1 - w_2 - w_3 - w_4$.

Table 6.10 Goodness of fit for each weight

| Statistic | $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ | $w_6$ | $w_7$ |
|---|---|---|---|---|---|---|---|
| $k$ | 0.0459 | 0.0541 | 0.0558 | 0.0461 | 0.0700 | 0.0810 | 0.0748 |
| $p$-value | 0.5800 | 0.3720 | 0.3351 | 0.5760 | 0.1223 | 0.0479 | 0.0827 |

To clarify the procedure with a numerical example, suppose agent 230 is activated. Then to find a value for $w_1$, the beta distribution in Figure 6.9 is sampled. Suppose this returns a value of 0.3613. Similarly, suppose the other weights are sampled from their beta distributions and the values are $w_2 = 0.1905$, $w_3 = 0.2136$, $w_4 = 0.3289$, and $w_7 = 0.4648$. Then $w_5 = 1 - 0.1905 - 0.2136 - 0.3289 = 0.267$ and $w_6 = 1 - 0.3613 - 0.4648 = 0.1739$.

The questionnaire item $Q_{10}$ concerns the comparison between recall timing and voluntariness. The purpose of this item, as mentioned earlier, is to evaluate the effect of recall timing and voluntariness on recreancy. Survey data on relative importance of recall timing and voluntariness are first transformed into ratios. As ratios range from 0 to 10, they are normalized using the following equation:

$$Y = \frac{X - a}{b - a} \tag{6.4}$$

where $Y$ is the normalized ratio, $X$ is the original ratio, $a$ is the lower bound of original ratios, and $b$ is the upper bound of original ratios.

Figure 6.16 demonstrates the frequency distribution and probability density function for relative importance of recall timing versus voluntariness. As shown in Figure 6.16, the frequency distribution is quite discrete. Ratios that fall in the interval $[0.9, 1]$ were dropped so that the normalized data are continuous and fitted into a standard beta distribution. The shape parameters for the distribution are 1.1275 and 6.6018. The Kolmogorov-Smirnov test statistic is 0.1866, and $p$-value is 3.0648e-08, which indicates that it is a very poor fit. However, this distribution is still used in the calibrated model as it makes the model straightforward to sample all the ratios from the same family of distributions. This is a limitation that needs to be recognized.
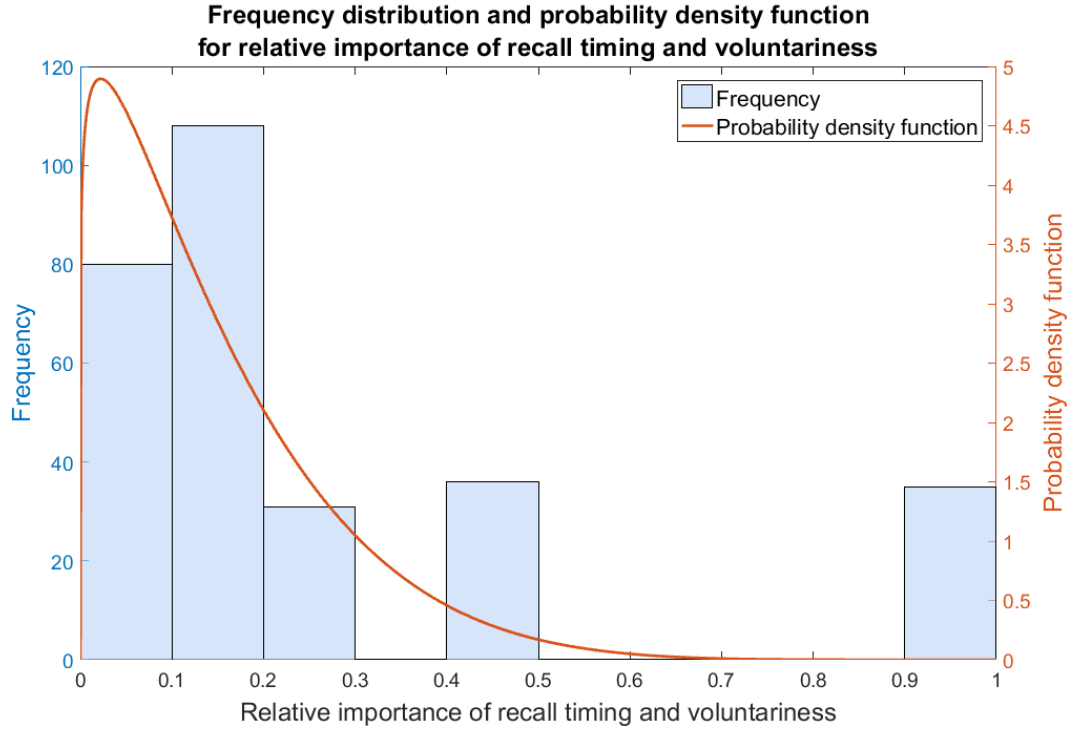
Figure 6.16 Frequency distribution and probability density function for relative importance of recall timing versus voluntariness

Ratios sampled from the standard beta distribution are transformed to those from a beta distribution with a lower bound $a$ and upper bound $b$:

$$X = Y(b-a) + a \qquad (6.5)$$

For each agent $i$ the ratio of recreancy increment by a recall to recreancy variation by voluntariness of a recall, i.e. $D_i/E_i$, is a number that is transformed from an observation sampled from the standard beta distribution. As $E_i$ cannot be calibrated through the survey, it is sampled from $[0, H)$ according to a uniform distribution. Accordingly, $D_i$ is the product of $E_i$ and the back-transformed ratio.

## 6.8 Simulation results of calibrated models

There are two sets of input parameters used in the simulation: 1) global input parameters that cannot be calibrated, 2) weights of each source of risk information that have been calibrated from the survey. Each agent $i$ is endowed with a threshold in risk perception $B_i$ sampled from $[0, S)$ and a variation in recreancy $E_i$ sampled from $[0, H)$ according to a uniform distribution. The input parameters and values used in the simulation of calibrated models are provided in Table 6.11.

Table 6.11 Input parameters and values used in the simulation of calibrated models

| Input parameter | Value | Description |
|---|---|---|
| Maximum initial condition $I$ | $10^{-4}$ | Defines initial risk and recreancy belief |
| Number of neighbours $K$ | 4 | Number of neighbours in a perfectly mixed population and in initial lattice |
| Rewiring probability $P$ | 0.5 | Probability of reconnecting a lattice edge |
| Low contamination level $C_{low}(t)$ | $10^{-4}$ | Level before and after crisis |
| High contamination level $C_{high}(t)$ | 0.2 | Level during the crisis |
| Contamination start period $T_{start}$ | 2000 | Time when the crisis starts |
| Contamination end period $T_{end}$ | 5999 | Time when the crisis ends |
| Recall voluntariness $v(t)$ | $\{0,1\}$ | Whether recall is voluntary or involuntary |
| Maximum perception threshold $S$ | 1 | Defines when a recall increases recreancy |
| Maximum recreancy variation $H$ | 1 | Maximum by which recreancy can change |

Figure 6.17 and Figure 6.18 show the results of a calibrated perfect mixing model in the context of voluntary recall and involuntary recall, respectively. Amplification of risk occurs irrespective of the role of media and voluntariness of recall. However, it appears that the objectivity of media coverage affects the degree of risk amplification inversely. The exogenous peaks emerge around the termination of the contamination, followed by a decline of risk perception after the crisis. And there are no fluctuations in the growth and decay of risk perception, illustrating that sampling different weights for agents does not cause much instability to the dynamics of social risk response. In addition, the case of involuntary recall exhibits a higher residue of concern than the case of voluntary recall. The reason is that after the crisis finishes an involuntary recall generates a higher level of recreancy that contributes to higher residual risk perception.

Figure 6.17 Trace of public risk perception in a single run of a calibrated perfect mixing model with voluntary recall ( $a(t=2008)=1$ , $v(t)=1$ )
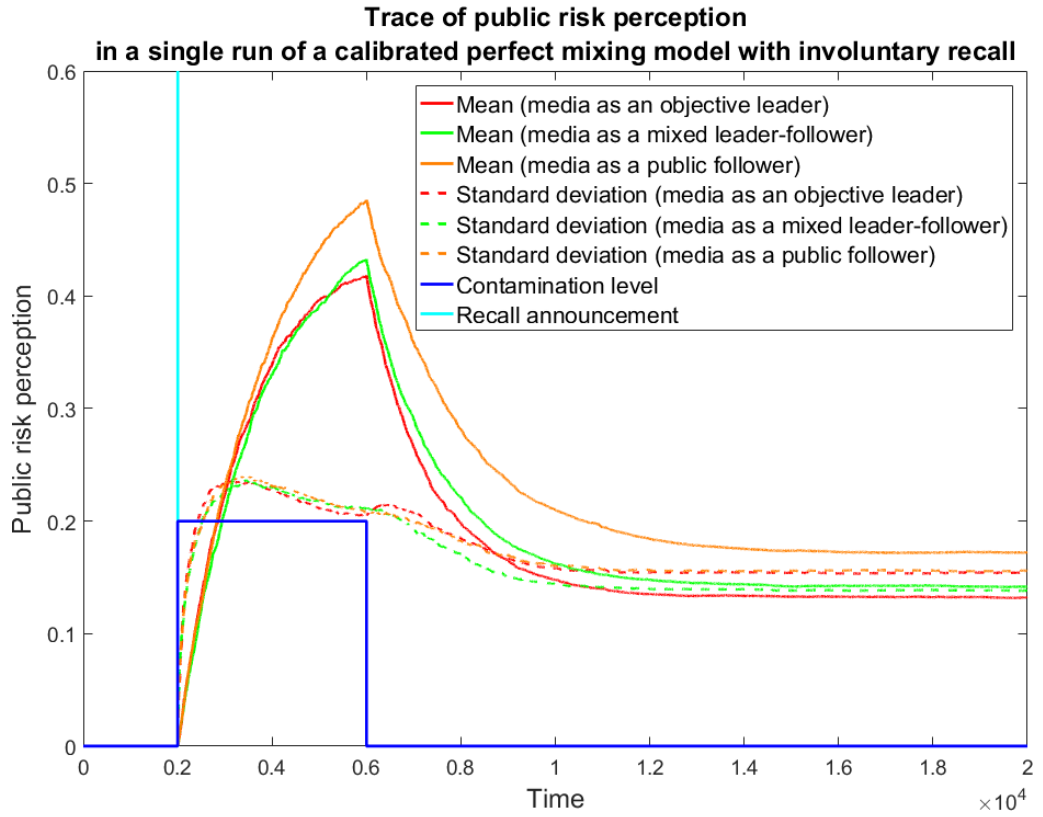


Figure 6.18 Trace of public risk perception in a single run of a calibrated perfect mixing model with involuntary recall ( $a(t=2003)=1$ , $v(t)=0$ )

Compared with the uncalibrated perfect mixing model (reproduced in Figure 6.19 and Figure 6.20), the calibrated model expresses a lower degree of risk amplification whatever the role the media assumes in the context of voluntary recall and a higher degree in the context of involuntary recall. This is mainly due to changes in the weight of recreancy. In the uncalibrated model 'recreancy' has a weight of 0.05 (Table 5.1), while in the calibrated model its mean weight is 0.1262 (Table 6.9). Voluntary recall leads to very low recreancy as it decreases an agent's recreancy belief, and involuntary recall is associated with relatively high recreancy as it increases recreancy belief. Therefore, a higher weight of 'recreancy' in the calibrated model to some degree diminishes risk amplification when the producer executes a voluntary recall and increases risk amplification when an involuntary recall is put into force. The higher weight of 'recreancy' also contributes to the high residual risk perception in the calibrated model in the context of involuntary recall. These results reveal how important the weight of 'recreancy' is for producing risk amplification, indicating that the kind of calibration presented in this study is particularly useful. Another difference is in the standard deviations – they are much higher in the calibrated model. This is to be expected as in the calibrated model the weights are sampled independently for each agent: in the original model agents all have the same weights.
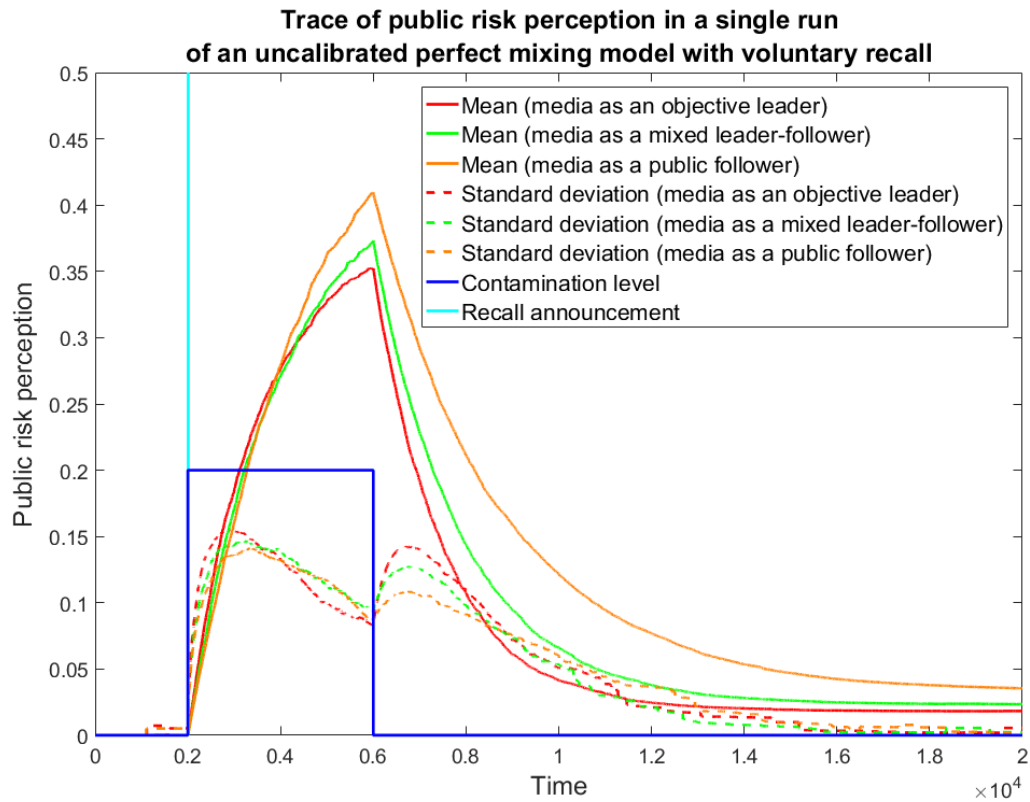


Figure 6.19 Trace of public risk perception in a single run of an uncalibrated perfect mixing model with voluntary recall ( $a(t=2008)=1$ , $v(t)=1$ )
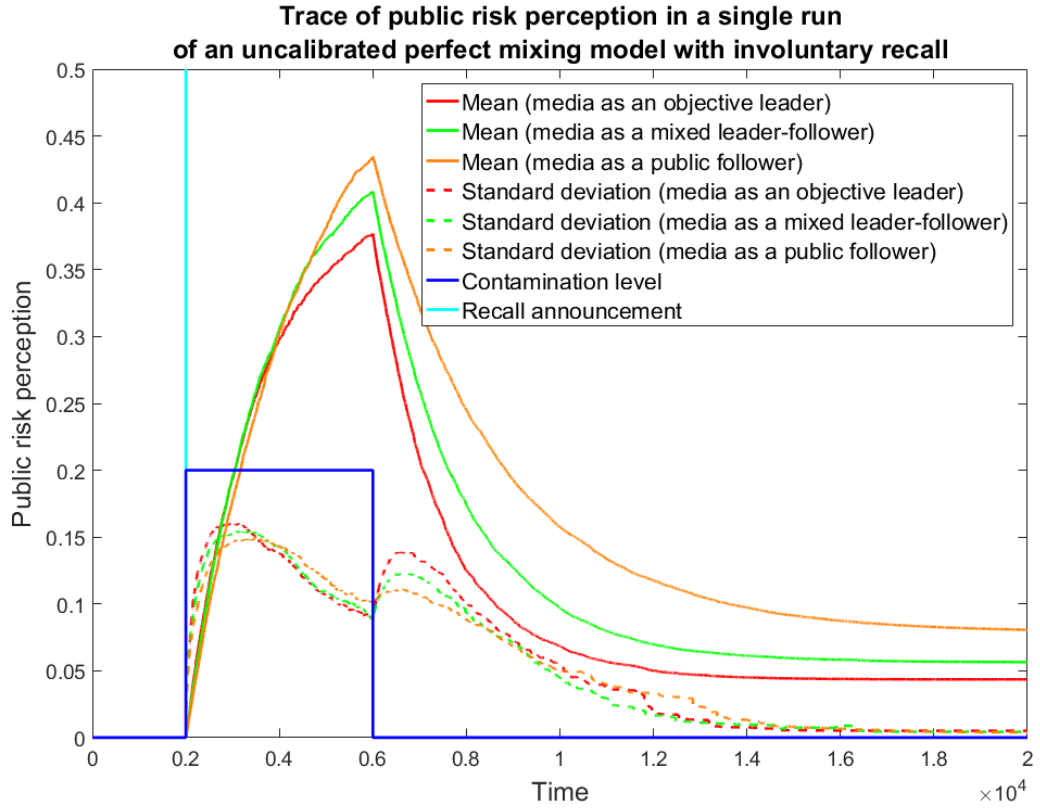
Figure 6.20 Trace of public risk perception in a single run of an uncalibrated perfect mixing model with involuntary recall ( $a(t=2003)=1$ , $v(t)=0$ )

Figure 6.21 and Figure 6.22 show the trace of public risk perception in a single run of a calibrated small-world network model with voluntary and involuntary recall, respectively. It seems that there is little difference in the qualitative features of time series of risk perceptions and a very small difference in the magnitude of risk amplification between the calibrated small-world network model and perfect mixing model. This is consistent with the comparison between the original small-world network model and perfect mixing model in Chapter 5. The indication is that the difference between the small-world network model and perfect mixing model has a low sensitivity to the specific weights used by agents.
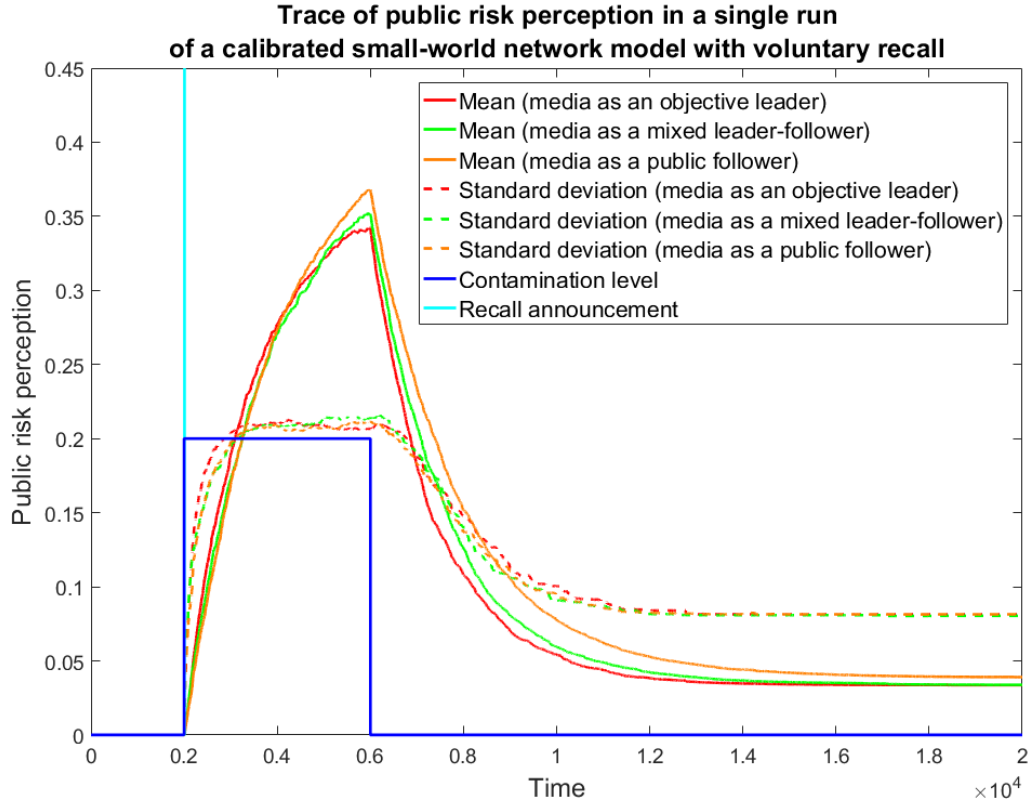
Figure 6.21 Trace of public risk perception in a single run of a calibrated small-world network model with voluntary recall ( $a(t = 2008) = 1$ , $v(t) = 1$ )
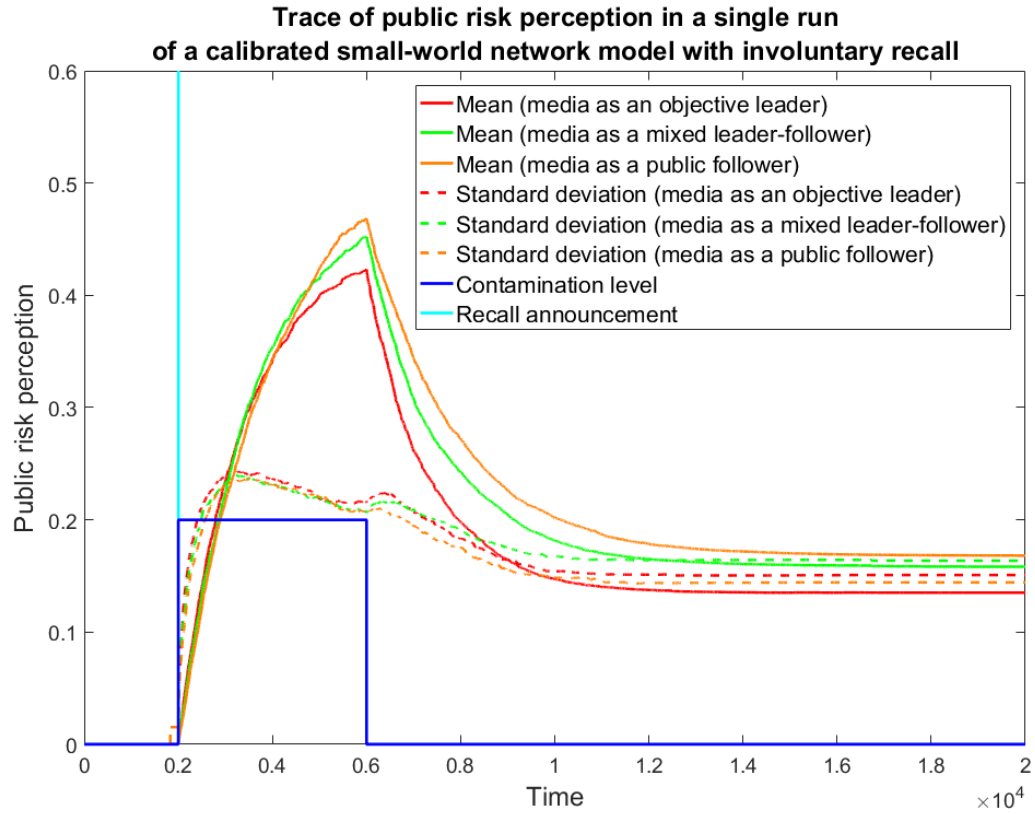


Figure 6.22 Trace of public risk perception in a single run of a calibrated small-world network model with involuntary recall ( $a(t = 2003) = 1$ , $v(t) = 0$ )

Comparison of the calibrated small-world network model with the original model with constant weights for all agents (reproduced in Figure 6.23 and Figure 6.24) is similar to the case of perfect mixing model indeed. The calibrated small-world network model produces a lower degree of risk amplification in the context of voluntary recall and a higher degree in the context of involuntary recall. Also, there is a higher residue of concern when the recall is made involuntarily, and standard deviations are much higher in both voluntary and involuntary recalls for the calibrated small-world network model.
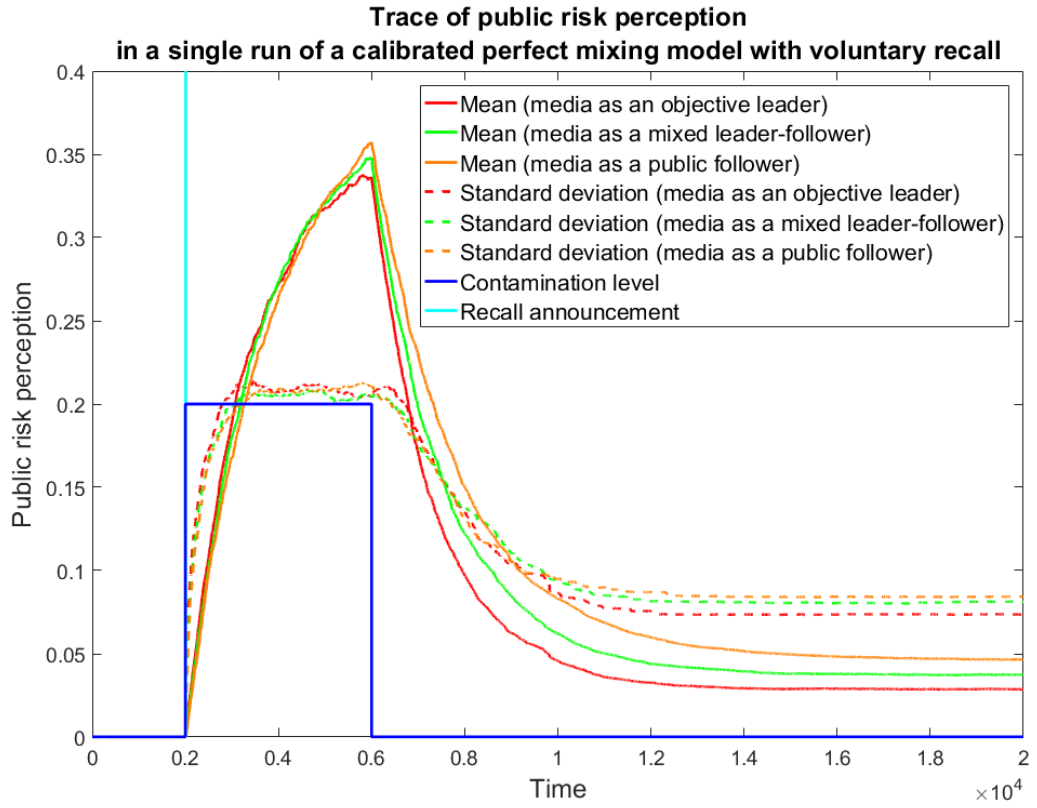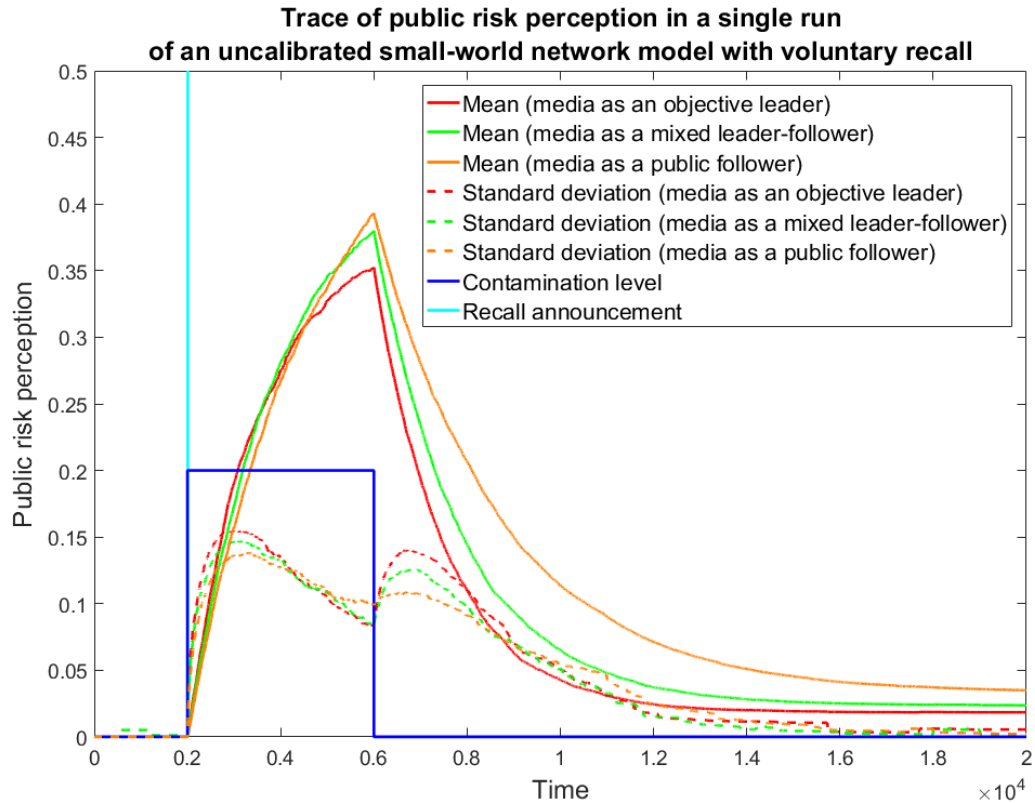


Figure 6.23 Trace of public risk perception in a single run of an uncalibrated small-world network model with voluntary recall ( $a(t=2008)=1$ , $v(t)=1$ )
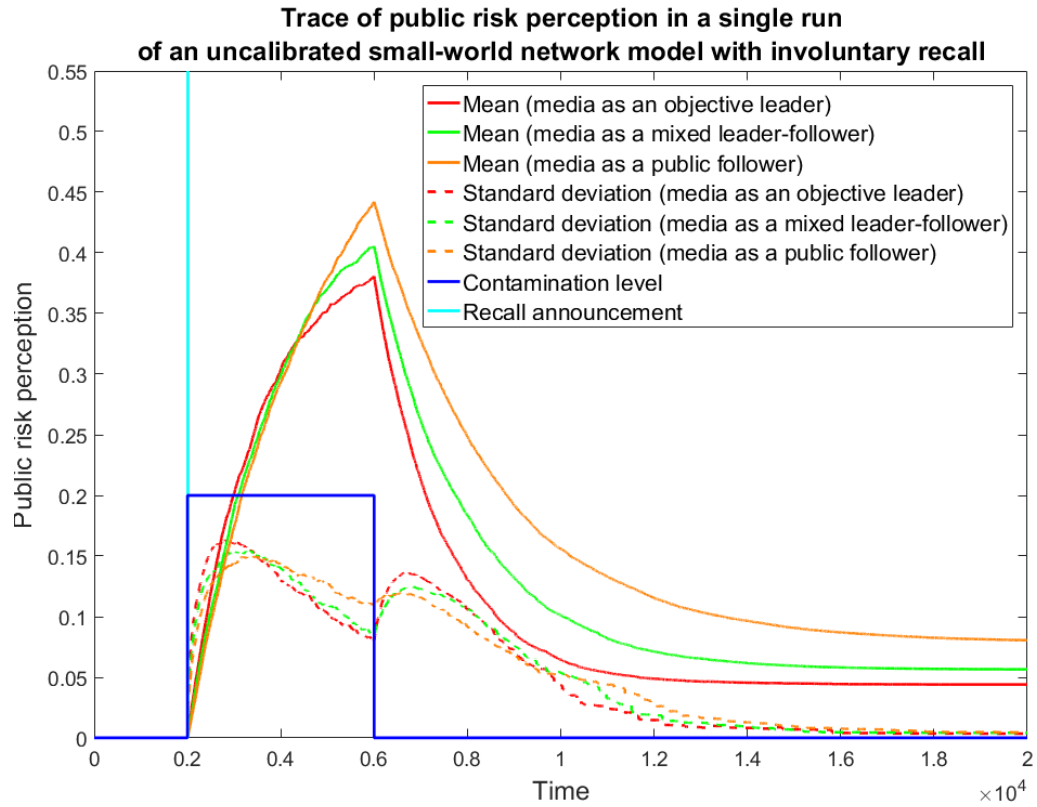
Figure 6.24 Trace of public risk perception in a single run of an uncalibrated small-world network model with involuntary recall ( $a(t = 2003) = 1$ , $v(t) = 0$ )

In summary, model calibration makes no difference to qualitative patterns of risk response, but it leads to a lower degree of risk amplification in the context of voluntary recall and a higher degree in the context of involuntary recall. Residual risk perception is also higher when the producer carries out the recall involuntarily. The model outcomes are relatively sensitive to the weights agents give to information sources. This demonstrates the importance of mixed weights in shaping risk perception and suggests that the calibration is essential for reducing the space of parameters and providing a certain level of micro-validity for the recall model.

# 7 TESTING THE MODEL

This chapter evaluates the uncertainty in model outputs and the validity of the model and consists of two parts, as shown in Figure 7.1. The first part concerns the sensitivity analysis that shows which are the most important aspects of the model in shaping social risk amplification. This part addresses sensitivity analysis in three aspects – the method used for sensitivity analysis, the results of sensitivity analysis, and the conclusions drawn from sensitivity analysis. The second part deals with the issue of model validity. This part first gives a brief literature review on validation of agent models, and then discusses validity of the recall model in terms of micro-validity and macro-validity. In summary, it will be demonstrated and argued that model outcomes are sensitive to the initial conditions, contamination level, contamination duration, and recreancy variation (in the case of involuntary recall), and that the model achieves a certain level of micro-validity and partial macro-validity.
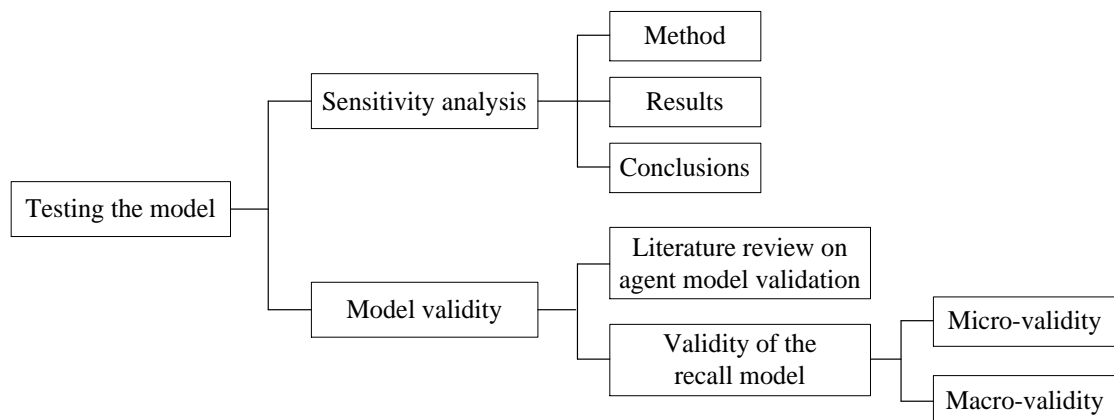
Figure 7.1 Structure of Chapter 7 Testing the Model

## 7.1 Sensitivity analysis

### 7.1.1 Method of sensitivity analysis

Sensitivity analysis plays an important role in understanding the relationship between model input parameters and important outputs that have some kind of theoretical or practical relevance. It helps assess how the uncertainty in model inputs impacts model outputs and helps identify the most significant parameters in the model. Trucano et al. (2006) have suggested that 'sensitivity analysis is required for understanding the extent to which a model is complicated enough to be credible but not too complicated'. A considerable number of

studies have conducted sensitivity analysis to evaluate the robustness of agent model results and to examine how the uncertainty in independent input variables can influence dependent output variables. The exercise of sensitivity analysis also aims to ensure that the model outputs comply with the theoretical assumptions and expectation underlying the model. In this case, it is of interest what parameters have the greatest influence on variations in the degree of social risk amplification as an outcome. Representing social risk amplification as a relatively complex mechanism means that the link between independent variables and the difference between objective and perceived risk becomes difficult to predict. Sensitivity analysis helps us understand how strong this link is, as an emergent property of the model.

Sensitivity analysis is commonly performed in *a qualitative way* by varying the value of testing parameters while keeping other parameters constant (Anderson et al., 2007; Grow et al., 2015; Jiang et al., 2016; Kimbrough and Murphy, 2013; Lee et al., 2013; Liu and Wu, 2016; Malik et al., 2015; Millington et al., 2014; Nagarajan et al., 2012; Okada, 2011; Stummer et al., 2015). For example, in an agent-based model of humanitarian assistance policies (Anderson et al., 2007), the authors studied the effect of all input parameters (levels of food and water, levels of security, medical personnel, medical resources, and sanitation) on the sickness rate of refugees. Each testing parameter was varied around its prior value while all other parameters were kept constant at their midpoints. Results show that the sickness rate decreases with the increase of levels of sanitation, security, medical resources, and medical personnel.

Occasional studies have made sensitivity explorations in *a quantitative way*. Zhang and Li (2014) considered an agent model of the search behaviour in China's resale housing market. They selected four parameters (matching efficiency, unit search cost, market tightness ratio, and broker commission rate) and one output (search intensity of both buyers and sellers) for the sensitivity analysis, and used the simple random sampling to estimate the correlation of each single input parameter with the output. The results show that the increase in the matching efficiency can reduce the search time of buyers and sellers significantly, but there is no evidence that the unit search cost exerts strong impact on the search time. In a more complex approach, Fonoberova et al. (2013) proposed a global sensitivity approach that evaluates the effect of a parameter while all other parameters are varied simultaneously. The measure is based on support-vector regression and thus takes account of the interactions between model parameters. The authors tested variance-based and derivative-based global sensitivity measure through an agent-based model of civil violence, and global sensitivity analysis was found to be capable of identifying the most significant and non-significant parameters in the model. Similarly, Kucherenko et al. (2009) also presented a derivative-based global sensitivity measures and provided evidence that their approach could be more efficient and more accurate than other sensitivity analysis techniques.

Sensitivity analysis in this study evaluates the main effect linking each of the model input parameters with defined outcome variables. More specifically, it examines the effect of one parameter with other parameters held constant at their default values. This simple approach was selected in order to make the sensitivity analysis straightforward to interpret. In principle, interaction effects between model parameters could be significant, and global sensitivity analysis could uncover variations in sensitivity over the parameter space. But these more complex analyses are demanding in the software for model evaluations and the amount of time to complete the analyses.

The analysis was conducted based on a calibrated small-world network model. Eight parameters (see Table 7.1) are considered significant for defining the global uncertainty in model outputs. Recall voluntariness $v(t)$ is not included as it is a binary variable, but the sensitivity analysis was performed in the case of both voluntary recall and involuntary recall. Parameters used in the sensitivity analysis are maximum initial condition $I$, number of neighbours $K$, rewiring probability $P$, low contamination level $C_{low}(t)$, high contamination level $C_{high}(t)$, contamination end period $T_{end}$ (contamination start period $T_{start}$ is fixed at 2000), maximum perception threshold $S$, and maximum recreancy variation $H$. In particular, certain starting conditions such as initial risk and recreancy belief are taken into account as difference was observed between results associated with a higher level of initial conditions and those in Chapter 5. According to the traces of risk perception in a single run in Section 5.2.2 and Section 5.3, contamination appears to have an impact on the occurrence and degree of risk amplification, so parameters pertaining to contamination are all included. Simulation results in 5.2.2 and Section 5.3 have proven recreancy to be influential in shaping risk responses, thus parameters related to recreancy belief are selected for sensitivity analysis.

Table 7.1 Input parameters used in sensitivity analysis

| Input parameter | Description |
| --- | --- |
| Maximum initial condition $I$ | Defines initial risk and recreancy belief |
| Number of neighbours $K$ | Number of neighbours in initial lattice |
| Rewiring probability $P$ | Probability of reconnecting a lattice edge |
| Low contamination level $C_{low}(t)$ | Level before and after crisis |
| High contamination level $C_{high}(t)$ | Level during the crisis |
| Contamination end period $T_{end}$ | Time when the crisis ends |
| Maximum perception threshold $S$ | Defines when a recall increases recreancy |
| Maximum recreancy variation $H$ | Maximum by which recreancy can change |

Four outcome variables provided in Table 7.2 are considered for the sensitivity analysis. They are mean risk amplification over crisis $\mu_m$, peak risk amplification $\mu_p$, peak delay from

crisis start $\varphi_c$, and peak delay from recall start $\varphi_r$. Mean risk amplification over crisis $\mu_m$ is associated with the mean degree of risk amplification during the contamination incident, and peak risk amplification $\mu_p$ involves the maximum discrepancy between public risk perception and the objective risk. The purpose of considering these two variables is to gain an insight into the relationship between input parameters and the degree of risk amplification. Peak delay from crisis start $\varphi_c$ and peak delay from recall start $\varphi_r$ are employed to explore how changes in model inputs affect the timing of risk amplification.

Table 7.2 Outcome variables used in sensitivity analysis

| Outcome variable | Description |
|---|---|
| Mean risk amplification over crisis $\mu_m$ | Mean ratio of public risk perception to the objective risk during the crisis |
| Peak risk amplification $\mu_p$ | Ratio of peak risk perception to the objective risk |
| Peak delay from crisis start $\varphi_c$ | Time delay between peak risk amplification and crisis start |
| Peak delay from recall start $\varphi_r$ | Time delay between peak risk amplification and recall start |

Mean risk amplification over crisis $\mu_m$ is the mean of ratio of public risk perception to the objective risk level during the crisis:

$$\mu_m = \frac{1}{Z}\sum_{j=1}^{Z}\frac{1}{T_{end}-T_{start}}\sum_{t=T_{start}}^{T_{end}}\frac{1}{N}\sum_{i=1}^{N}\left(b_i(t)/C_{high}(t)\right) \tag{7.1}$$

where $N$, $T_{start}$, $T_{end}$, $Z$, and $C_{high}(t)$ denote the number of agents, crisis start period, crisis end period, the number of runs, and the contamination level during the crisis. Peak risk amplification $\mu_p$ is defined as the ratio between peak risk perception and the objective risk level:

$$\mu_p = \frac{1}{Z}\sum_{j=1}^{Z}\left(\max\left(\frac{1}{N}\sum_{i=1}^{N}b_i(t)\right)/C_{high}(t)\right) \tag{7.2}$$

where $N$ and $Z$ signify the number of agents and number of runs, and $C_{high}(t)$ is the contamination level during the crisis (fixed during the crisis). Peak delay from crisis start $\varphi_c$ refers to the time delay from the start of the crisis to the occurrence of peak risk amplification:

$$\varphi_c = \frac{1}{Z}\sum_{j=1}^{Z}\left(T_{peak}\left(\mu_s = \max\left(\frac{1}{N}\sum_{i=1}^{N}b_i(t)\right)\right)-T_{start}\right) \tag{7.3}$$

where $T_{peak}$ represents the time when peak risk perception in a single run $\mu_s$ arises, $T_{start}$ is the time when the crisis starts, and $N$ and $Z$ signify the number of agents and number of

model runs. Similarly, peak delay from recall start $\varphi_r$ is defined as the delay between the start of recall and peak risk amplification:

$$\varphi_r = \frac{1}{Z} \sum_{j=1}^{Z} \left( T_{peak} \left( \mu_s = \max \left( \frac{1}{N} \sum_{i=1}^{N} b_i(t) \right) \right) - T_{a(t)=1} \right) \tag{7.4}$$

where $T_{peak}$ denotes the time when peak risk perception in a single run $\mu_s$ emerges, $T_{a(t)=1}$ indicates the time when a recall announcement is made, and $N$ is the number of agents, and $Z$ represents the number of times the model is replicated.

The approach used for sensitivity analysis in this study is one-at-a-time (OAT), which is the simplest and most widely used approach seen in the literature. It evaluates the effect of one parameter at a time with all other parameters left at base values shown in Table 6.11. Varying one factor at a time means that the effect observed on the output is due solely to that factor so makes interpretation simpler. Another important consideration is that the computational cost (i.e. the number of times the model has to be evaluated) is relatively low when dealing with thousands of simulations, which is actually the case in this study.

Each parameter is sampled 200 times uniformly from a specified range provided in Table 7.3. The maximum and minimum selected for each parameter are a subjective choice, but they are believed to encompass the reasonably likely range of each parameter. Parameters are sampled uniformly, first, because no particular assumption is then made about the distribution of input parameters. Second, this study concentrates on exploring how sensitive the model outputs are to the variations of model inputs rather than performing an uncertainty analysis to describe the distribution of possible outcomes given uncertainty about a set of inputs with known distributions. Some scholars have used a uniform distribution to draw samples of input parameters within specific spaces and obtained sensible sensitivity analysis results (Fonoberova et al., 2013; Nagarajan et al., 2012).

Table 7.3 Sample range of input parameters

| Input parameter | Range | Base value |
|---|---|---|
| Maximum initial condition $I$ | [0, 1] | $10^{-4}$ |
| Number of neighbours $K$ | [2, 50] | 4 |
| Rewiring probability $P$ | [0, 1] | 0.5 |
| Low contamination level $C_{low}(t)$ | $[10^{-6}, 10^{-3}]$ | $10^{-4}$ |
| High contamination level $C_{high}(t)$ | $[2 \times 10^{-4}, 1]$ | 0.2 |
| Contamination end period $T_{end}$ | $[3 \times 10^3, 16 \times 10^3]$ | 5999 |
| Maximum perception threshold $S$ | [0, 1] | 1 |
| Maximum recreancy variation $H$ | [0, 1] | 1 |

For each sample the model is run 100 times for the duration of 20,000 periods with 1,000 agents in a small-world network. Pearson product-moment correlation coefficient is calculated to analyse the impact of each considered parameters. In this way the model outcome variables are numerically compared. However, OAT 'is predicated on assumptions of model linearity' (Saltelli and Annoni, 2010), and Pearson's correlation coefficient measures the fitness of a linear correlation between two variables. As a consequence, scatter plots, together with associated least-squares approximation, of outcome variables against individual input variables are plotted to visually depict the correlations.

## 7.1.2 Results of sensitivity analysis

In this section only the most interesting relationships will be explained. These are the relationships where 1) the effect on the outcome variable is quite large, 2) the relationship is non-linear, and 3) there is some implication for real world behaviour. The results are presented by outcome variable, and both correlation coefficients and scatter plots are given.

### *First outcome variable: mean risk amplification over crisis*

Table 7.4 shows simple product moment correlations between input parameters and mean risk amplification over crisis $\mu_m$ in a calibrated small-world network model in the case of voluntary recall and involuntary recall. The results show that this outcome has a perfect positive linear relationship with maximum initial condition $I$ (which effectively is the maximum initial risk belief in the population). This is to be expected as high initial belief associates with high mean public risk perception over the crisis. There is a strong positive correlation (correlations range from 0.9 to 0.94) between this outcome and contamination end period $T_{end}$. More agents get activated in a longer duration of contamination, so risk perception is amplified to a relatively higher degree. Mean risk amplification over crisis $\mu_m$ is inversely correlated with high contamination level $C_{high}(t)$ (level during the crisis), with correlations ranging from -0.44 to -0.24. This agrees with the observations from Section 5.2.2 and Section 5.3 that during the crisis the degree of risk amplification decreases with the level of contamination.

No dependence is found on maximum perception threshold $S$ (which defines when a recall increases recreancy). The correlation coefficients range from -0.15 to 0.06, and correlations are non-significant at the 0.05 significance level except the case where media is an objective leader and a recall is made voluntarily. As described in Section 5.2.1, the most likely delay of recall timing is 1 tick only, so the time span between the start of crisis and the announcement

of recall is quite short, resulting in a very minimal impact of this parameter on recreancy belief and risk amplification. This outcome is unrelated to maximum recreancy variation $H$ (maximum by which recreancy can change) in the case of voluntary recall. Agents will decrease their recreancy belief if a recall is made voluntarily, but recreancy belief prior to recall (which is actually the initial recreancy belief) is very small, so the impact of this parameter is insignificant. In contrast, there is a perfect positive linear relationship when an involuntary recall is in force, since an involuntary recall acts to increase recreancy belief and subsequently risk perception.

Mean risk amplification over crisis $\mu_m$ is not related to the network parameters: number of neighbours $K$ and rewiring probability $P$. This suggests that this output is insensitive to the topology of the social network. The explanations for this result are given in Chapter 8. There is also insensitivity to low contamination level $C_{low}(t)$ (level before and after crisis). As the value of this parameter is very low, it indicates a very low probability of experiencing the contamination before and after crisis. Therefore, it can make almost no difference to mean risk amplification over crisis $\mu_m$.

Table 7.4 Correlation coefficients between input parameters and mean risk amplification over crisis

| Input parameter | Voluntary recall | | | Involuntary recall | | |
|---|---|---|---|---|---|---|
| | Objective leader | Mixed leader-follower | Public follower | Objective leader | Mixed leader-follower | Public follower |
| Maximum initial condition $I$ | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of neighbours $K$ | 0.02 | -0.16 | 0.05 | -0.07 | 0.03 | -0.1 |
| Rewiring probability $P$ | 0.12 | 0.01 | -0.18 | -0.05 | 0.08 | 0.13 |
| Low contamination level $C_{low}(t)$ | 0.02 | 0.03 | 0.07 | 0.1 | 0.2 | -0.05 |
| High contamination level $C_{high}(t)$ | -0.43 | -0.14 | -0.34 | -0.3 | -0.24 | -0.44 |
| Contamination end period $T_{end}$ | 0.91 | 0.92 | 0.94 | 0.9 | 0.91 | 0.94 |
| Maximum perception threshold $S$ | -0.15 | 0.03 | -0.09 | -0.11 | 0.06 | -0.1 |
| Maximum recreancy variation $H$ | 0.05 | 0.1 | -0.12 | 1 | 1 | 1 |

The following scatter plots show visually where there are non-linear relationships between independent variables and mean risk amplification over the crisis. Figure 7.2 and Figure 7.3 display the relationships between mean risk amplification over crisis and the level of contamination during the crisis with both voluntary and involuntary recalls. To show risk amplification more clearly, a base 10 logarithmic scale is used for the Y axis that denotes mean risk amplification. As shown in the figures, there is a rapid decrease of mean risk amplification as the contamination level rises, but the rate of decrease also declines quite rapidly. The reason risk amplification is so high when the peak contamination is very low is

that low contamination is associated with a low probability of making a recall, contributing to continuous increase in recreancy belief and risk perception. Mean risk amplification over crisis drops to less than 1 when the objective risk exceeds a certain level (around 0.28). This indicates that social risk amplification only occurs when the objective risk level is below some threshold.



Figure 7.2 Sensitivity analysis of high contamination level on mean risk amplification over crisis for a calibrated small-world network model with voluntary recall

Figure 7.3 Sensitivity analysis of high contamination level on mean risk amplification over crisis for a calibrated small-world network model with involuntary recall

Figure 7.4 and Figure 7.5 depict the nonlinear relationships between mean risk amplification over the crisis and contamination end period. Mean risk amplification experiences a rapid increase with contamination end period when each agent is activated less than or equal to five times on average during the contamination period (contamination start time $T_{start}$ is fixed at 2000). If each agent is activated more than five times, the rise will decay. This is because the longer the duration of contamination, the more likely agents are to be influenced by the risk issue, and the more likely that risk responses are heightened. But public perceptions of risk tend to become homogeneous as the duration of the contamination incident increases, which leads to a relatively slow increase in risk amplification.

In reality, individuals collect risk information from a variety of sources to adjust their risk estimates during the crisis. Long duration of contamination enables individuals to discover more pieces of information. As the duration is prolonged, undetected risk information becomes less available, and individuals are more likely to be exposed to the same set of information and develop a global consensual judgment of risk. The increase of risk amplification will then slow down. This is a significant effect, because it suggests that an organization coping with a crisis, and trying to avoid strong risk amplification, needs to limit the duration, but that as this duration becomes larger, it experiences much less incentive to do so. In other words, once a crisis has gone on for a certain length of time, there is not an increasing incentive to resolve it.

Figure 7.4 Sensitivity analysis of contamination end period on mean risk amplification over crisis for a calibrated small-world network model with voluntary recall
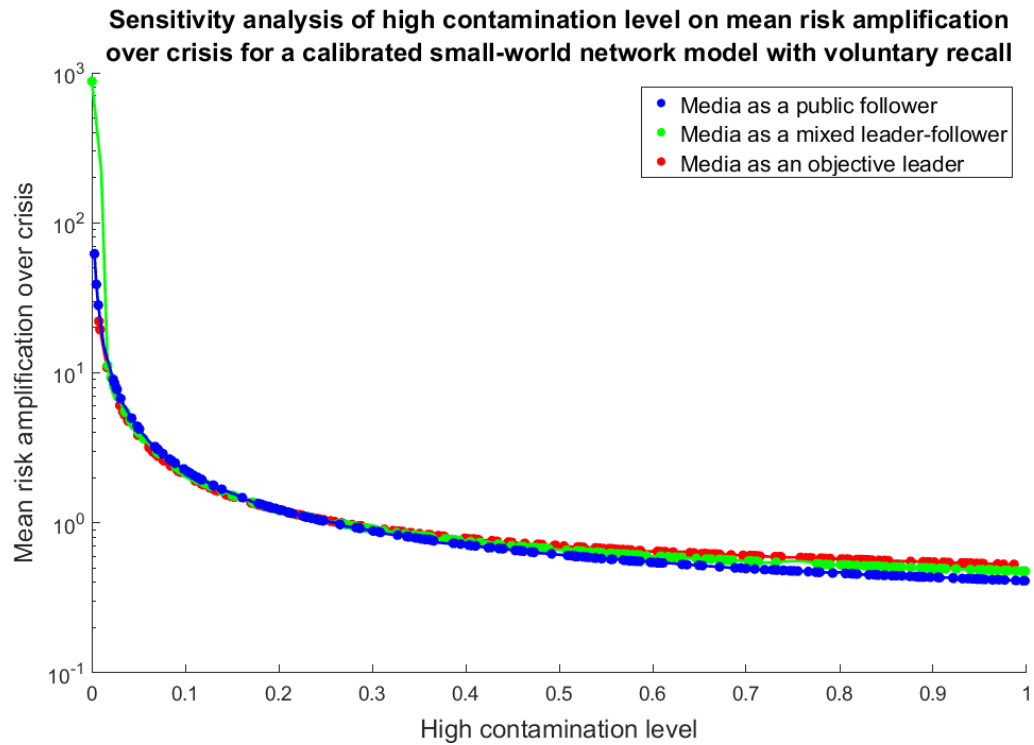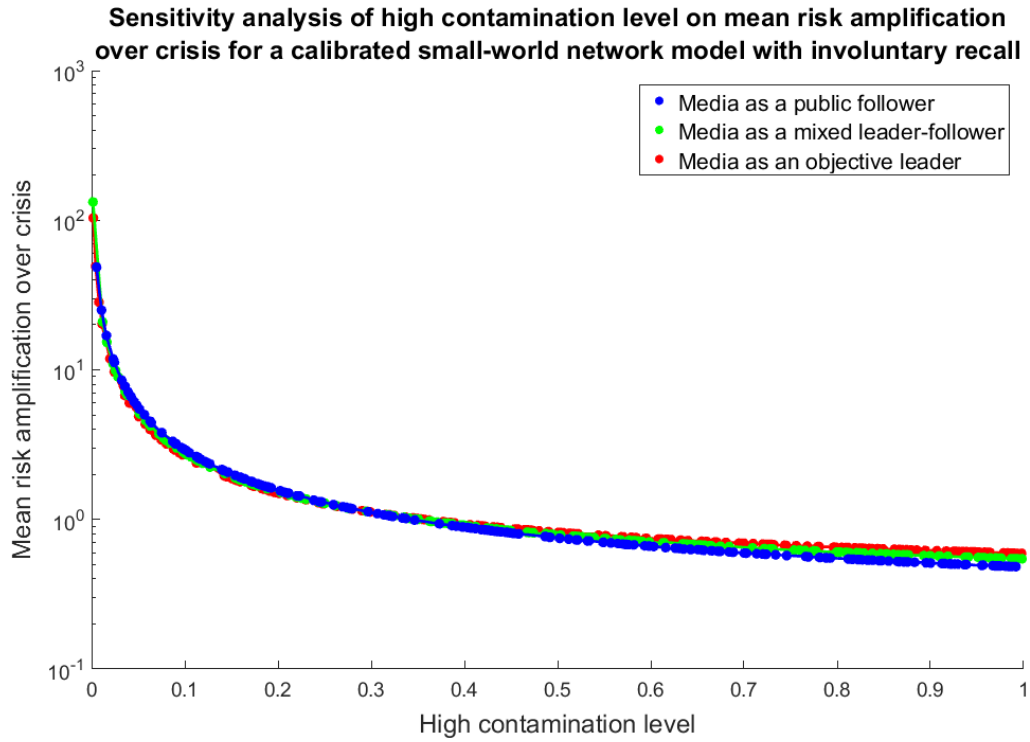


Figure 7.5 Sensitivity analysis of contamination end period on mean risk amplification over crisis for a calibrated small-world network model with involuntary recall

## Second outcome variable: peak risk amplification

Table 7.5 provides the correlation coefficients between input parameters and peak risk amplification $\mu_p$. The statistics show that this outcome has a strong positive relationship with maximum initial condition $I$ (correlations range from 0.86 to 0.99) and contamination end period $T_{end}$ (correlations range from 0.73 to 0.82). Peak risk amplification $\mu_p$ is very sensitive to maximum recreancy variation $H$ in the case of involuntary recall. It is moderately correlated with high contamination level $C_{high}(t)$, with correlations ranging from -0.4 to -0.19. In addition, no association is found between this outcome and other parameters including number of neighbours $K$, rewiring probability $P$, low contamination level $C_{low}(t)$, maximum perception threshold $S$, and maximum recreancy variation $H$ in the case of voluntary recall.

Peak risk amplification $\mu_p$ is quite similar to mean risk amplification over crisis $\mu_m$ in terms of their relationships with input parameters. This is not surprising as these two variables are closely related. Peak risk amplification generally occurs around the time when the contamination ceases. Mean risk amplification over the crisis practically varies with peak risk amplification: if peak risk amplification is high, mean risk amplification over the crisis will be high, and vice versa. Therefore, the explanations for the correlations between mean risk amplification over crisis $\mu_m$ and input parameters also apply here.

Table 7.5 Correlation coefficients between input parameters and peak risk amplification

| Input parameter | Voluntary recall | | | Involuntary recall | | |
|---|---|---|---|---|---|---|
| | Objective leader | Mixed leader-follower | Public follower | Objective leader | Mixed leader-follower | Public follower |
| Maximum initial condition $I$ | 0.86 | 0.88 | 0.96 | 0.99 | 0.99 | 0.99 |
| Number of neighbours $K$ | -0.1 | -0.02 | -0.21 | -0.01 | 0.07 | 0.07 |
| Rewiring probability $P$ | 0 | 0.04 | -0.11 | -0.04 | 0.17 | 0.07 |
| Low contamination level $C_{low}(t)$ | -0.02 | 0.07 | 0.15 | -0.12 | -0.16 | 0.12 |
| High contamination level $C_{high}(t)$ | -0.26 | -0.4 | -0.38 | -0.33 | -0.19 | -0.38 |
| Contamination end period $T_{end}$ | 0.73 | 0.78 | 0.81 | 0.76 | 0.77 | 0.82 |
| Maximum perception threshold $S$ | 0.11 | -0.04 | -0.11 | -0.02 | -0.06 | -0.11 |
| Maximum recreancy variation $H$ | 0.06 | -0.08 | -0.13 | 1 | 1 | 1 |

The following scatter plots present the nonlinear relationships between peak risk amplification and input parameters. Figure 7.6 shows the relationship between peak risk amplification and maximum initial condition – the upper bound defining the range of initial

risk perceptions at the start of the simulation – in the context of voluntary recall. Peak risk amplification increases slowly with the initial condition, but it then surges as the initial condition rises. This is because at some point, the initial risk belief is at a level which makes it the highest risk belief during the simulation. This is a pretty pathological condition, implying that people are so worried that a new contamination crisis cannot increase their worry. But it shows again that risk amplification is affected by a society's status quo, and is independent of external effects when the initial risk belief is high enough.



Figure 7.6 Sensitivity analysis of maximum initial condition on peak risk amplification for a calibrated small-world network model with voluntary recall

Figure 7.7 and Figure 7.8 illustrate the sensitivity of peak risk amplification to high contamination level in the context of voluntary and involuntary recall, respectively. A base 10 logarithmic scale is used for peak risk amplification on the Y axis. The qualitative pattern of these two figures is similar to that of Figure 7.2 and Figure 7.3 regarding mean risk amplification over crisis. There is a sharp decline of peak risk amplification, followed by a slow decrease, as high contamination level increases. Risk amplification will not occur if the contamination level is high enough. This suggests that in a recall event where the objective risk is very high it is unlikely that the risk becomes heightened. Interestingly, it has long been known that people over-estimate low risks in general, and under-estimate high ones (Viscusi, 1992). The model is consistent with this – and perhaps provides an alternative explanation.
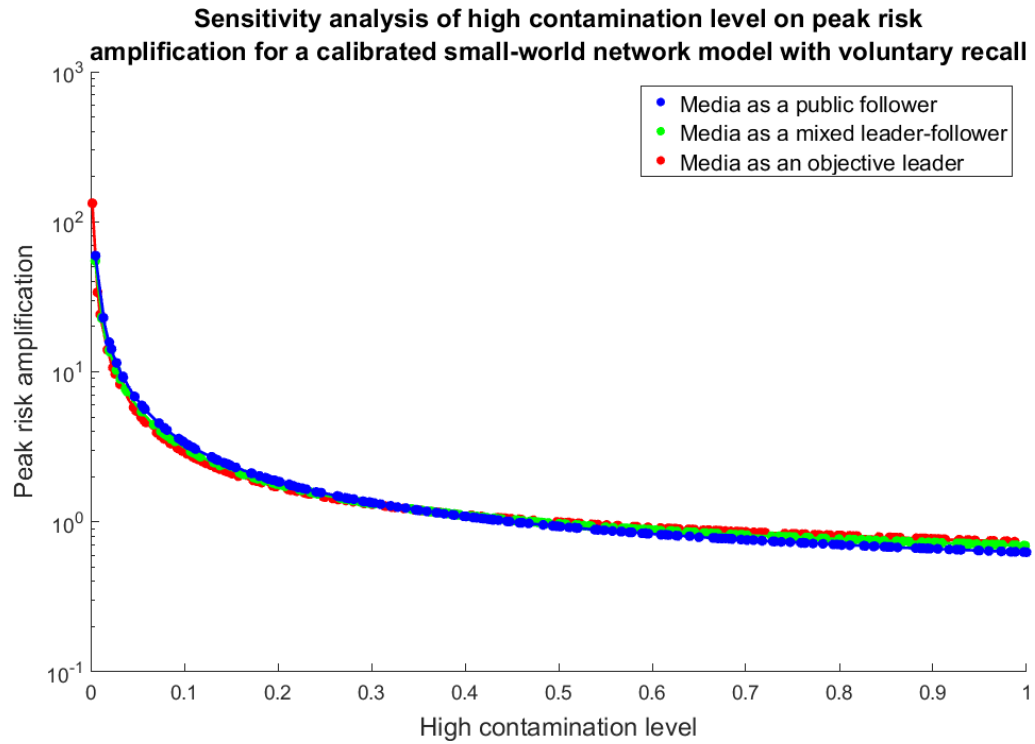
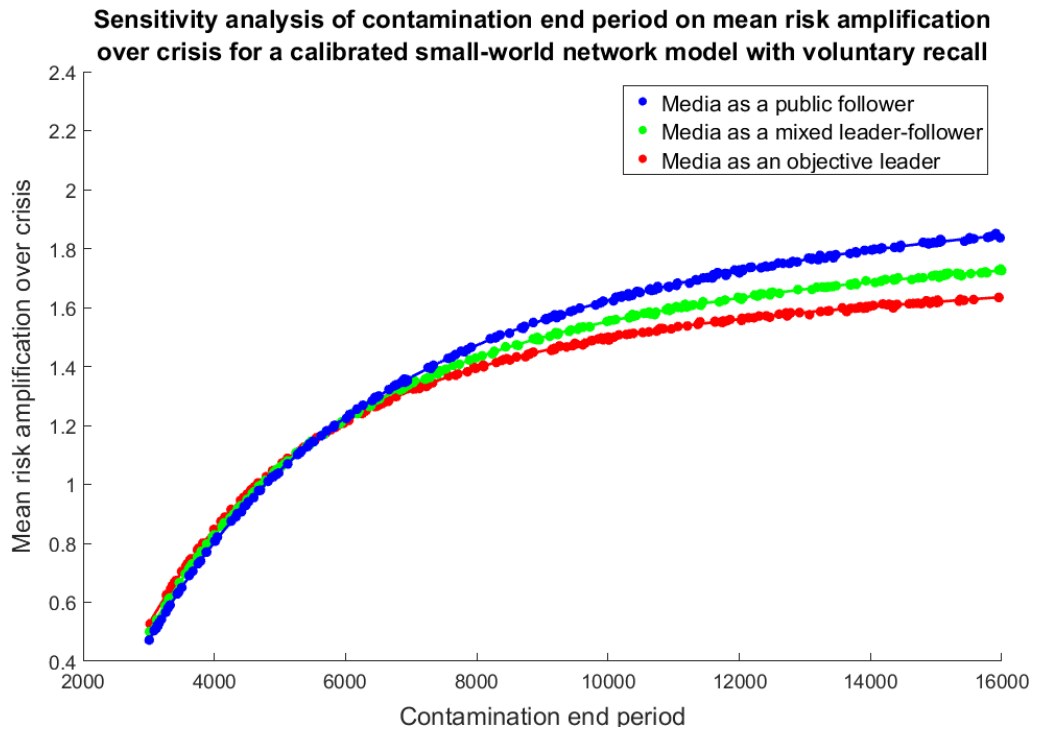Figure 7.7 Sensitivity analysis of high contamination level on peak risk amplification for a calibrated small-world network model with voluntary recall
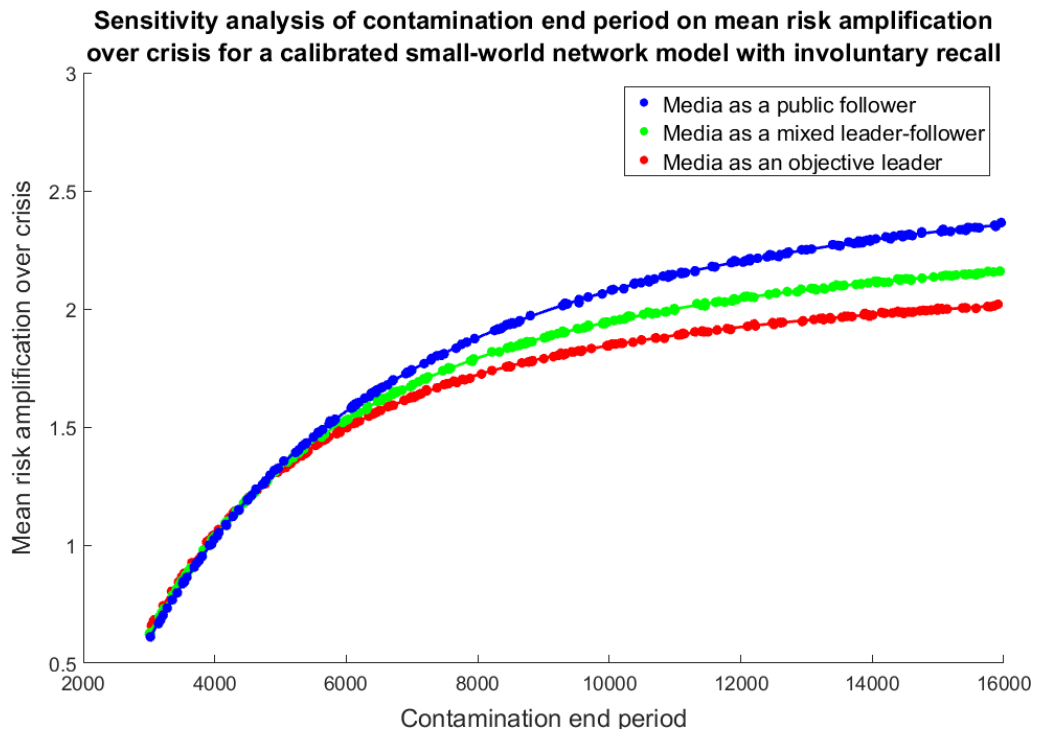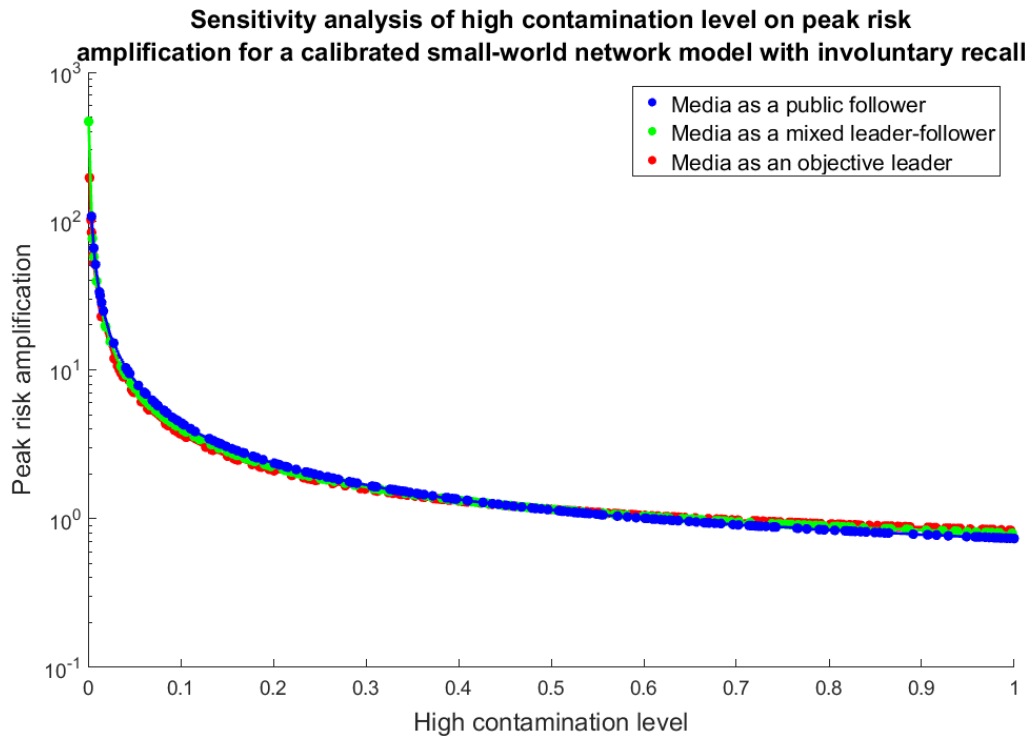


Figure 7.8 Sensitivity analysis of high contamination level on peak risk amplification for a calibrated small-world network model with involuntary recall

Figure 7.9 and Figure 7.10 show the relationships between peak risk amplification and contamination end period with both voluntary and involuntary recalls. Also, the figures are

similar to those for mean risk amplification over crisis (Figure 7.4 and Figure 7.5) in terms of qualitative features. Peak risk amplification increases rapidly when the duration of contamination is less than 4,000 periods, but it then rises quite slowly when the duration is longer than 4,000 periods. The length of duration affects the number of times each agent is activated, which contributes to the formation of risk beliefs. Another insight is that there is an inverse relation between the objectivity of media coverage and this outcome. Risk is exaggerated to a much higher level when the media simply follows public opinion. This is in line with the simulation results from Section 5.2.2 and Section 5.3.
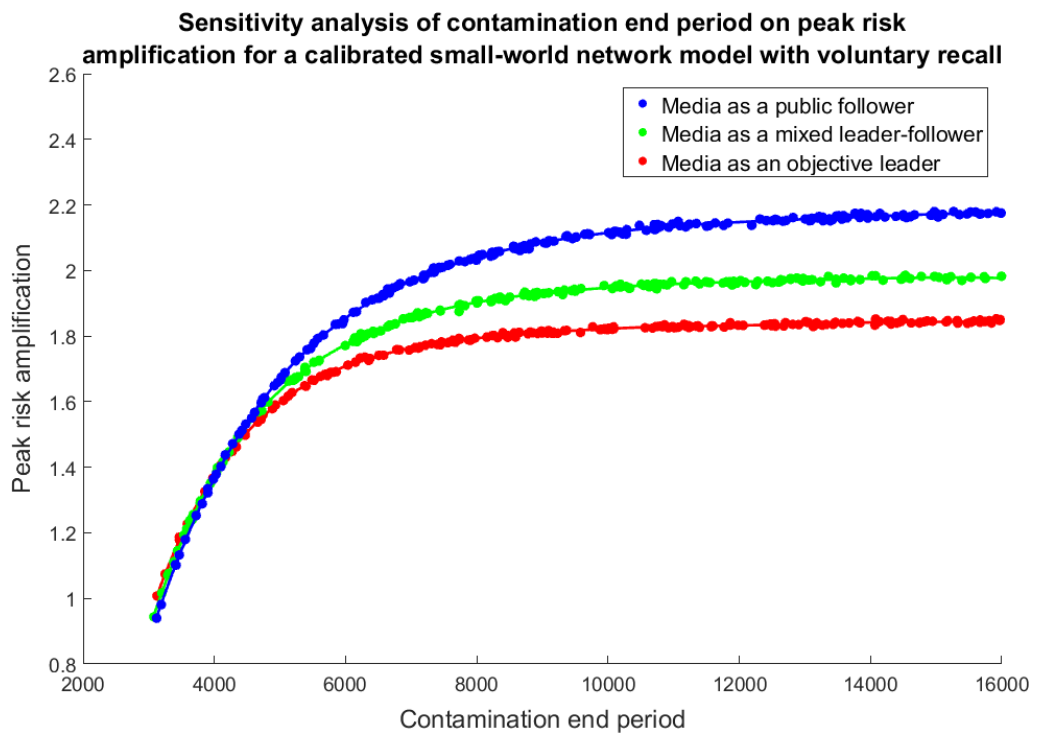


Figure 7.9 Sensitivity analysis of contamination end period on peak risk amplification for a calibrated small-world network model with voluntary recall
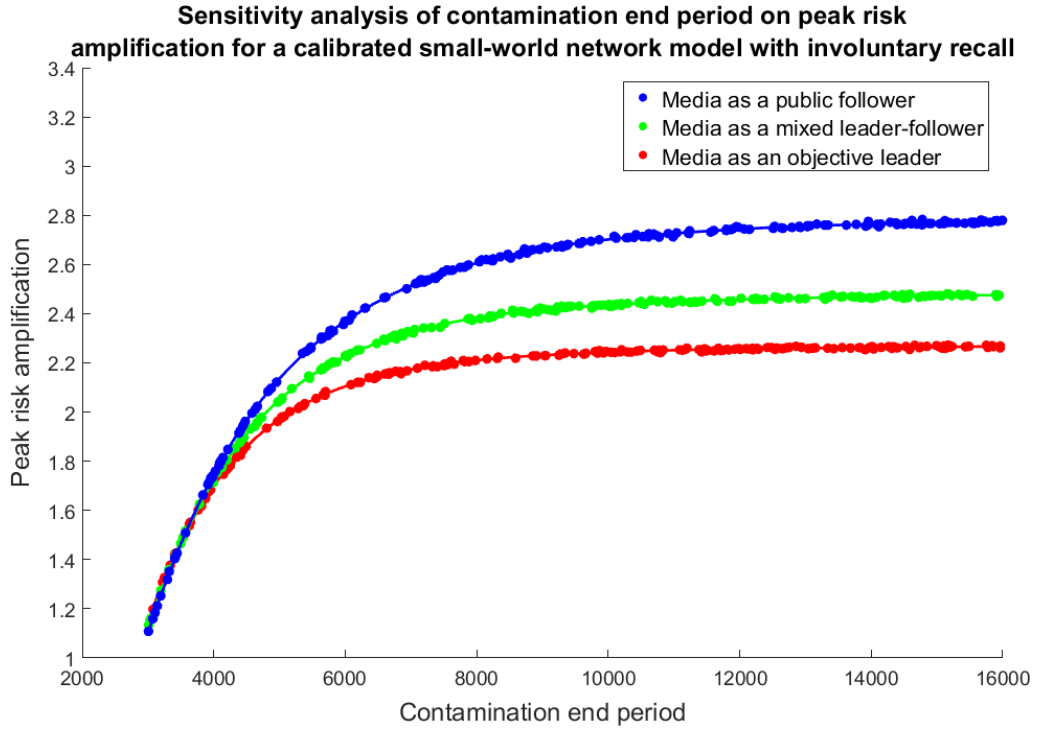
Figure 7.10 Sensitivity analysis of contamination end period on peak risk amplification for a calibrated small-world network model with involuntary recall

## *Third outcome variable: peak delay from crisis start*

The correlations between model input parameters and peak delay from crisis start $\varphi_c$ (crisis start time $T_{start}$ is fixed at 2000) are given in Table 7.6. This outcome has a strong negative relationship with maximum initial condition $I$, with correlations ranging from -0.79 to -0.43. It is positively related to high contamination level $C_{high}(t)$, with correlations ranging from 0.32 to 0.67. The reasons will be discussed later when it comes to scatter plots. There is a perfect positive linear correlation between this outcome and contamination end period $T_{end}$. Because peak risk amplification generally emerges when the crisis is coming to an end, the longer the contamination lasts, the longer it takes to generate peak risk amplification. Peak delay from crisis start $\varphi_c$ is positively correlated with maximum recreancy variation $H$ in the context of involuntary recall (correlations range from 0.45 to 0.58). When a producer issues a recall involuntarily, recreancy is increased by some increment and prolongs the timing of peak risk amplification.

As evident from Table 7.6, peak delay from crisis start $\varphi_c$ is insensitive to number of neighbours $K$, rewiring probability $P$, low contamination level $C_{low}(t)$, maximum perception threshold $S$, and maximum recreancy variation $H$ (in the case of voluntary

recall). This is because, as discussed earlier, these independent variables do not contribute to the development of risk responses.

Table 7.6 Correlation coefficients between input parameters and peak delay from crisis start

| Input parameter | Voluntary recall | | | Involuntary recall | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Objective leader | Mixed leader-follower | Public follower | Objective leader | Mixed leader-follower | Public follower |
| Maximum initial condition $I$ | -0.79 | -0.72 | -0.6 | -0.43 | -0.62 | -0.67 |
| Number of neighbours $K$ | 0 | -0.1 | 0.01 | -0.09 | 0 | 0.12 |
| Rewiring probability $P$ | 0.01 | 0.07 | -0.12 | 0 | -0.1 | 0.01 |
| Low contamination level $C_{low}(t)$ | -0.13 | 0.04 | -0.02 | -0.09 | -0.02 | -0.08 |
| High contamination level $C_{high}(t)$ | 0.67 | 0.52 | 0.32 | 0.53 | 0.62 | 0.36 |
| Contamination end period $T_{end}$ | 0.99 | 1 | 1 | 0.99 | 1 | 1 |
| Maximum perception threshold $S$ | -0.05 | -0.01 | -0.38 | -0.01 | -0.11 | 0 |
| Maximum recreancy variation $H$ | 0.01 | 0.04 | 0.04 | 0.47 | 0.45 | 0.58 |

The following scatter plots show visually where there are non-linear relationships between independent variables and peak delay from crisis start. Figure 7.11 and Figure 7.12 illustrate the relationships between maximum initial condition and peak delay from the start of crisis with both voluntary and involuntary recalls. This outcome appears to be a piecewise linear function of maximum initial risk belief that consists of three line segments. Peak delay is constant in both the first and the third line segments. This is to be expected. The model does not introduce much randomness, so changes in the initial conditions can make little difference to the timing of peak risk amplification. In particular, Figure 7.11 shows that when a recall is made voluntarily, there is a transition of the delay from a positive value in the first line segment to a negative value in the third line segment. This is because, as explained earlier, risk amplification peaks at the start of the model when the initial risk belief reaches a certain value. This is not true for Figure 7.12 where the peak delay is positive all the time. Peak risk amplification generally occurs around the end of the crisis due to the significant negative impact of an involuntary recall on risk perception.
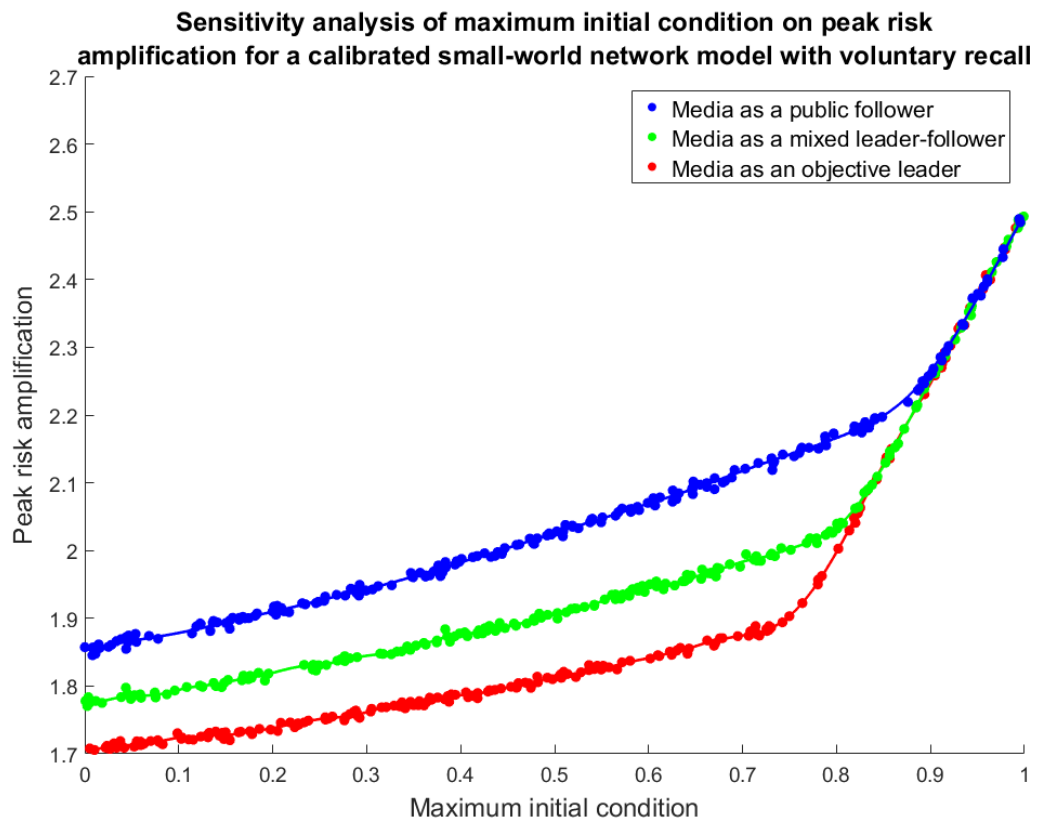
Figure 7.11 Sensitivity analysis of maximum initial condition on peak delay from crisis start for a calibrated small-world network model with voluntary recall



Figure 7.12 Sensitivity analysis of maximum initial condition on peak delay from crisis start for a calibrated small-world network model with involuntary recall

Figure 7.13 and Figure 7.14 show that there is a U-shaped relationship between peak delay from crisis start and high contamination level. There is a turning point where the time delay between the start time of crisis and timing of peak risk amplification is the minimum. The delay decreases quickly with high contamination level, but it then increases slowly as high contamination level rises. In the model high contamination level is associated with the probability of experiencing contamination, the probability of issuing a recall, and media communicated risk during the crisis. It may be that there is a point at which the impact of different amplification stations on risk perception is the most significant and to the largest extent shortens the time required to reach peak risk perception. And this point is effectively the turning point displayed in the figures. Another observation is that the objectivity of media coverage is positively related to the level of contamination that indicates the shortest delay between peak risk amplification and the start of crisis. The more objective the media reporting, the larger the contamination level at the turning point.



Figure 7.13 Sensitivity analysis of high contamination level on peak delay from crisis start for a calibrated small-world network model with voluntary recall

Figure 7.14 Sensitivity analysis of high contamination level on peak delay from crisis start for a calibrated small-world network model with involuntary recall

## *Fourth outcome variable: peak delay from recall start*

Table 7.7 presents the correlations between input parameters and peak delay from recall start $\varphi_r$. This outcome has a negative relationship with maximum initial condition $I$ (correlations range from -0.78 to -0.37), and a positive relationship with high contamination level $C_{high}(t)$ (correlations range from 0.44 to 0.83) and maximum recreancy variation $H$ in the case of involuntary recall (correlations range from 0.54 to 0.58). It has a perfect positive linear relationship with contamination end period $T_{end}$. Peak delay from recall start $\varphi_r$ is insensitive to number of neighbours $K$, rewiring probability $P$, low contamination level $C_{low}(t)$, maximum perception threshold $S$, and maximum recreancy variation $H$ (in the case of voluntary recall).

The relationships are similar to those between independent variables and peak delay from crisis start $\varphi_c$. In the model the recall announcement is random, leading to a fairly short time span between the time when the contamination is first revealed and the time when the recall is issued. Therefore, the difference between peak delay from recall start $\varphi_r$ and peak delay from crisis start $\varphi_c$ is very small. The explanations for the correlations between input parameters and peak delay from crisis start $\varphi_c$ are applicable here as well.

Table 7.7 Correlation coefficients between input parameters and peak delay from recall start

| Input parameter | Voluntary recall | | | Involuntary recall | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Objective leader | Mixed leader-follower | Public follower | Objective leader | Mixed leader-follower | Public follower |
| Maximum initial condition $I$ | -0.78 | -0.66 | -0.62 | -0.37 | -0.73 | -0.66 |
| Number of neighbours $K$ | 0.01 | 0.08 | -0.01 | -0.01 | -0.25 | 0 |
| Rewiring probability $P$ | 0.06 | -0.1 | -0.08 | -0.09 | 0.03 | -0.08 |
| Low contamination level $C_{low}(t)$ | 0.02 | 0.03 | 0.05 | -0.02 | 0.11 | -0.04 |
| High contamination level $C_{high}(t)$ | 0.44 | 0.83 | 0.65 | 0.62 | 0.53 | 0.6 |
| Contamination end period $T_{end}$ | 0.99 | 1 | 1 | 0.99 | 1 | 1 |
| Maximum perception threshold $S$ | -0.05 | -0.05 | -0.33 | -0.1 | 0.12 | -0.07 |
| Maximum recreancy variation $H$ | -0.03 | 0.1 | 0.21 | 0.54 | 0.57 | 0.58 |

Figure 7.15 and Figure 7.16 show the relationships between maximum initial condition and peak delay from recall start. This outcome is a piecewise linear function of initial risk belief with three line segments. The explanations provided for the relationships between maximum initial condition and peak delay from crisis start (Figure 7.11 and Figure 7.12) apply here.
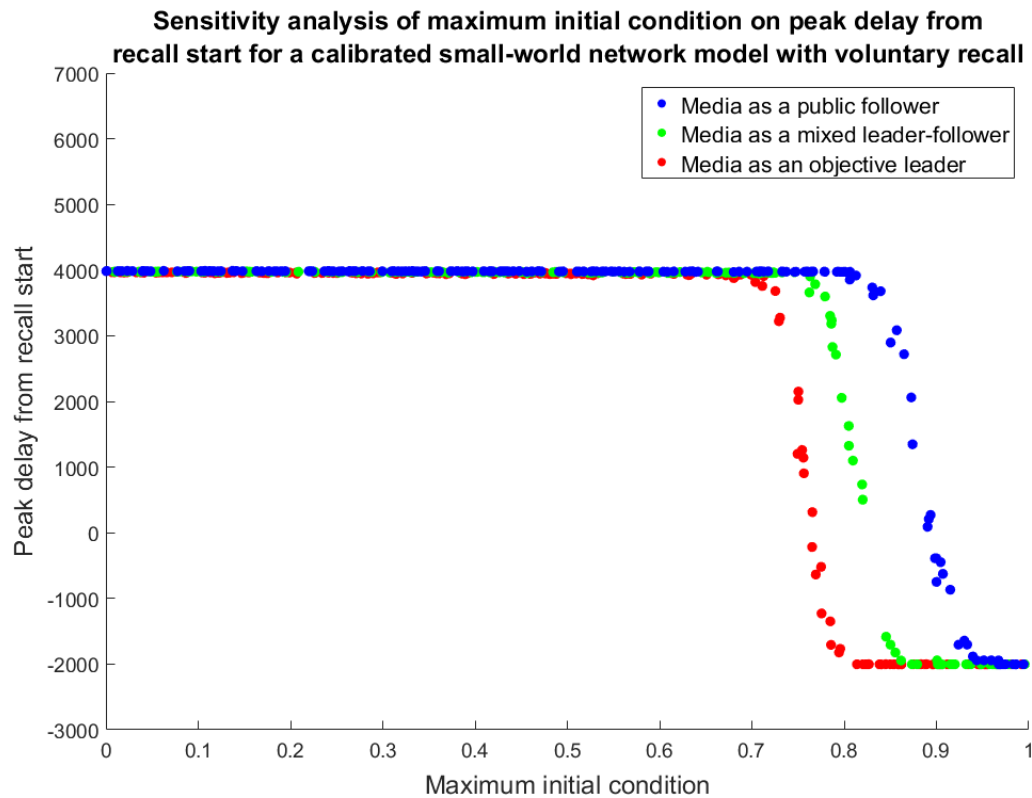


Figure 7.15 Sensitivity analysis of maximum initial condition on peak delay from recall start for a calibrated small-world network model with voluntary recall
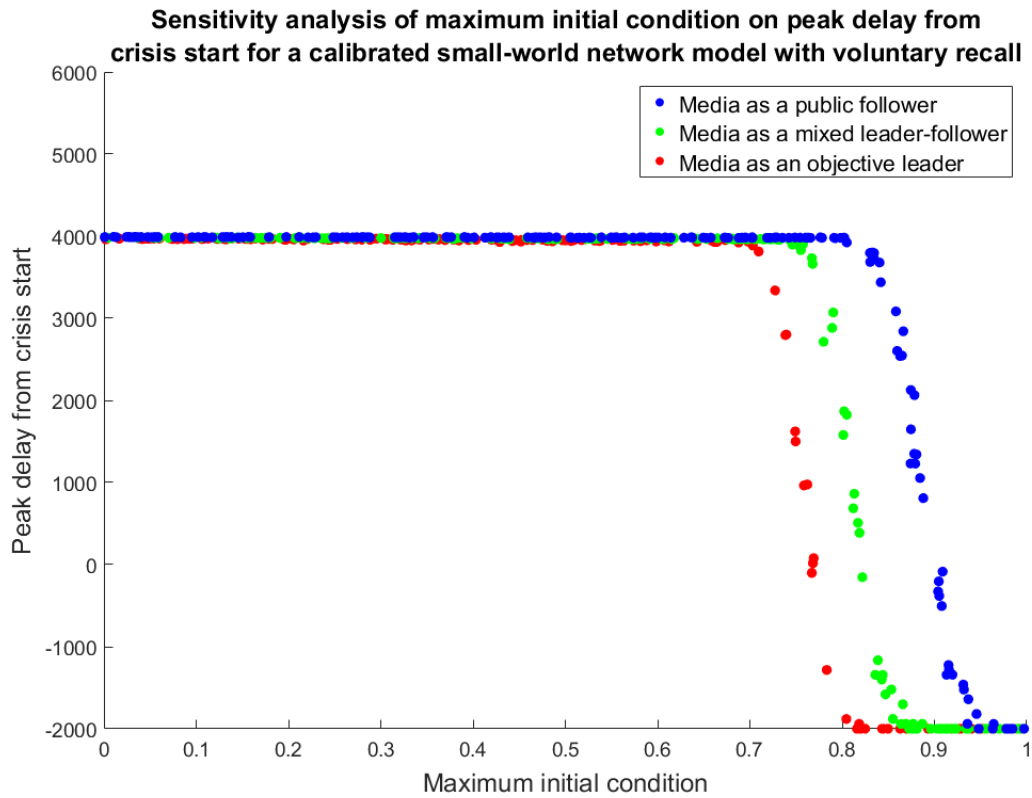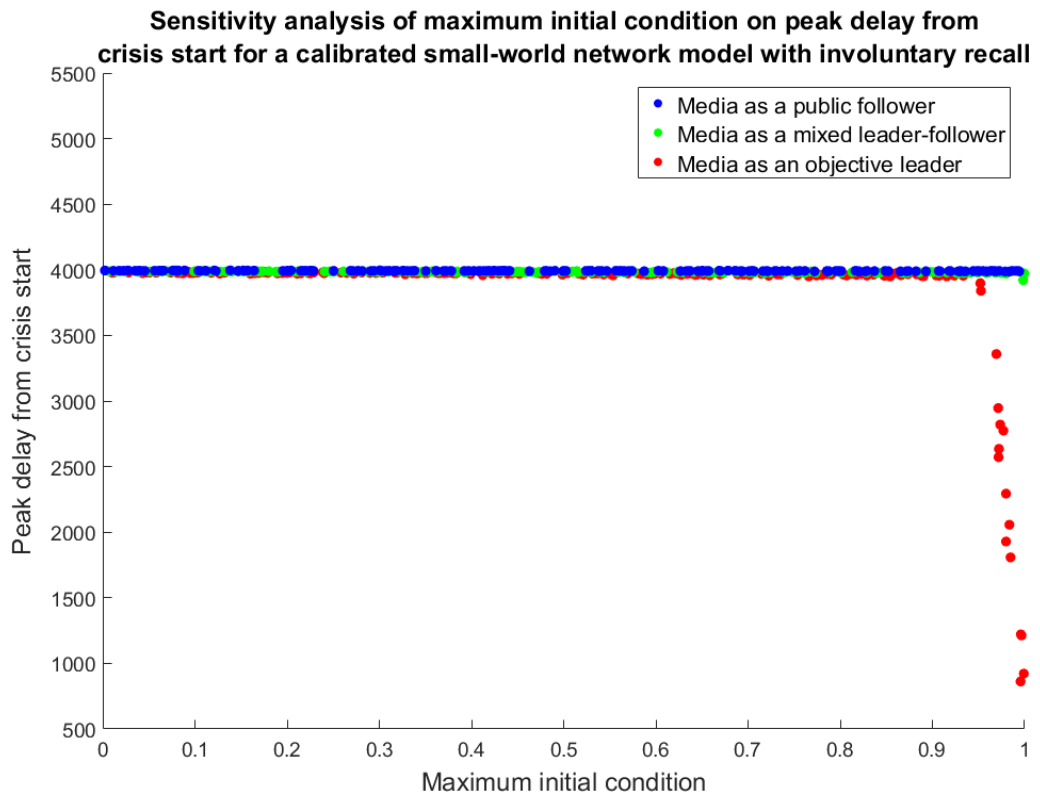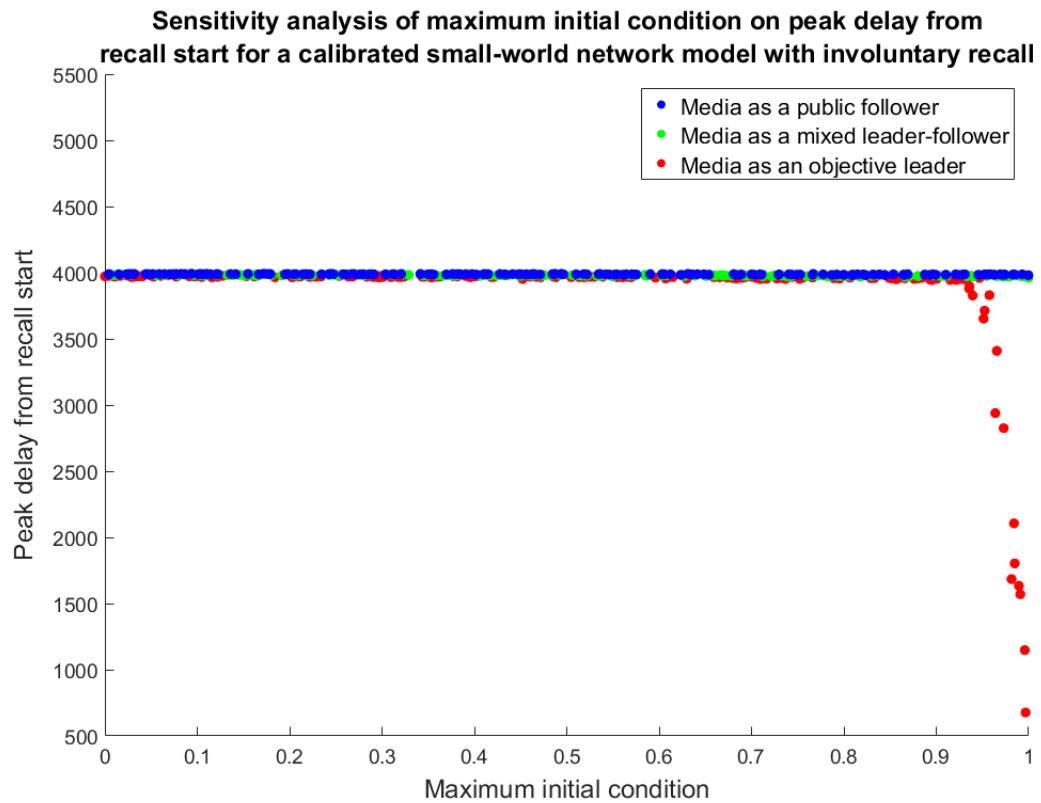
Figure 7.16 Sensitivity analysis of maximum initial condition on peak delay from recall start for a calibrated small-world network model with involuntary recall

Figure 7.17 and Figure 7.18 illustrate the relationships between peak delay from recall start and high contamination level with both voluntary and involuntary recalls. The delay experiences a steep rise and then stays almost unchanged when the contamination level increases. In the model high contamination level represents the probability of issuing a recall during the crisis. The larger the contamination level, the earlier the timing of product recall. At the same time, the contamination level affects media communicated risk and direct experience. The larger the contamination level, the stronger the impact of media and direct experience on risk perception, the earlier the timing of peak risk perception. As a result, the delay of peak risk amplification from the start of recall is almost constant across most values of contamination level. There are some occasional cases in which both the contamination level and the delay are lower. A low probability of issuing a recall increases recreancy and leads to an extremely high degree of risk amplification in a short time, reducing the time span between peak risk amplification and the start of recall.
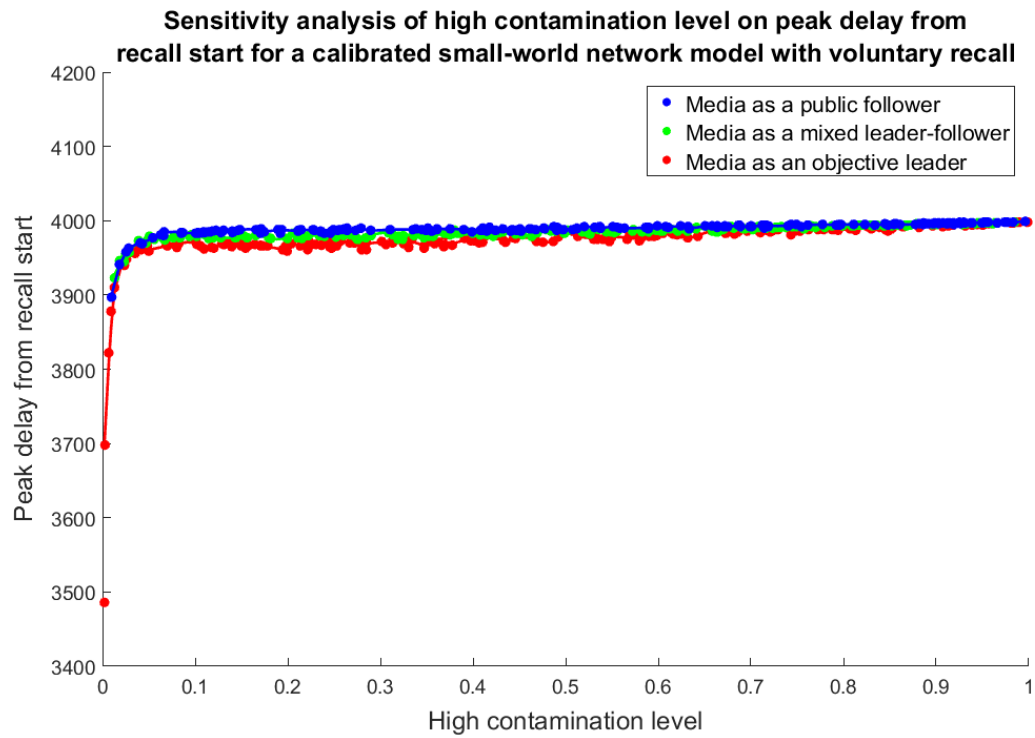
Figure 7.17 Sensitivity analysis of high contamination level on peak delay from recall start for a calibrated small-world network model with voluntary recall



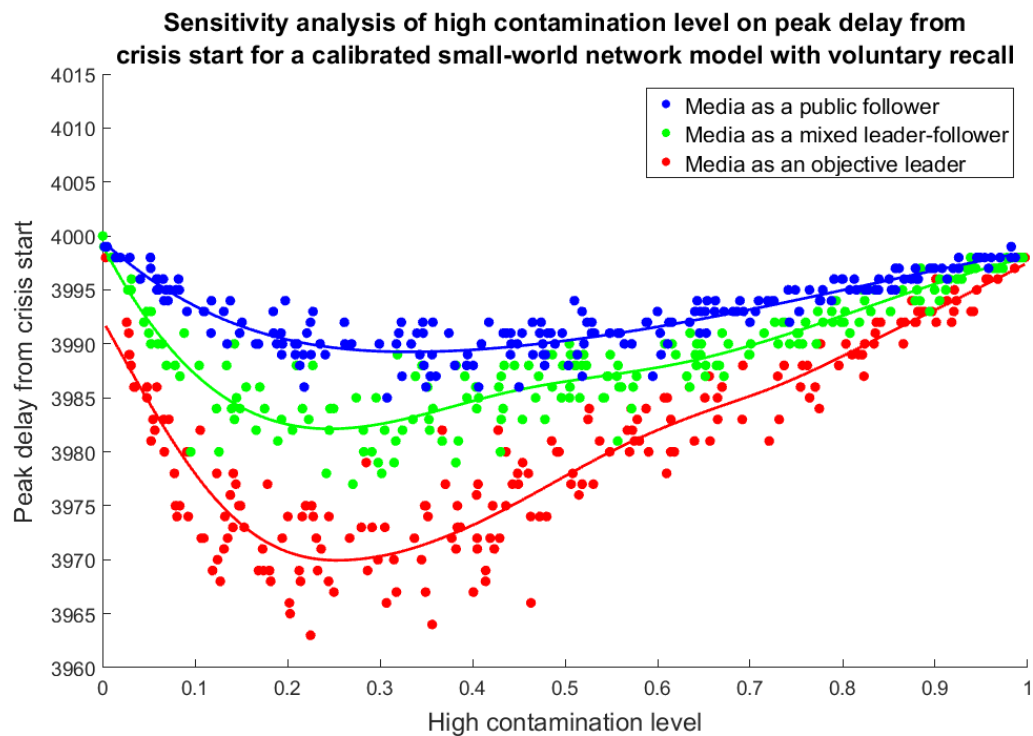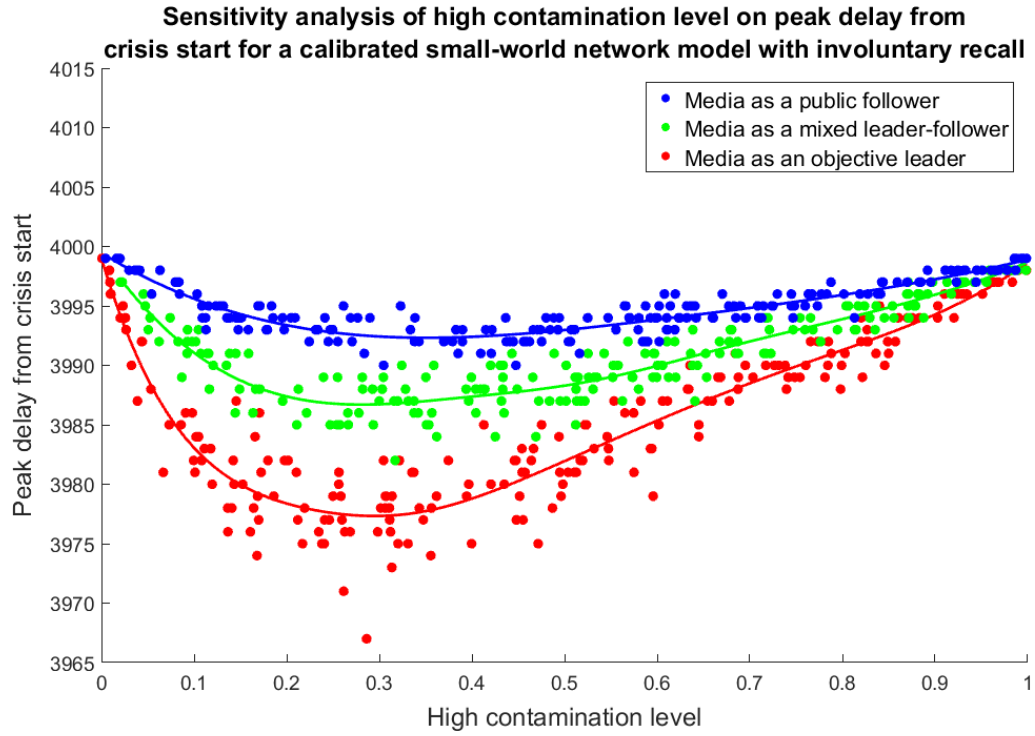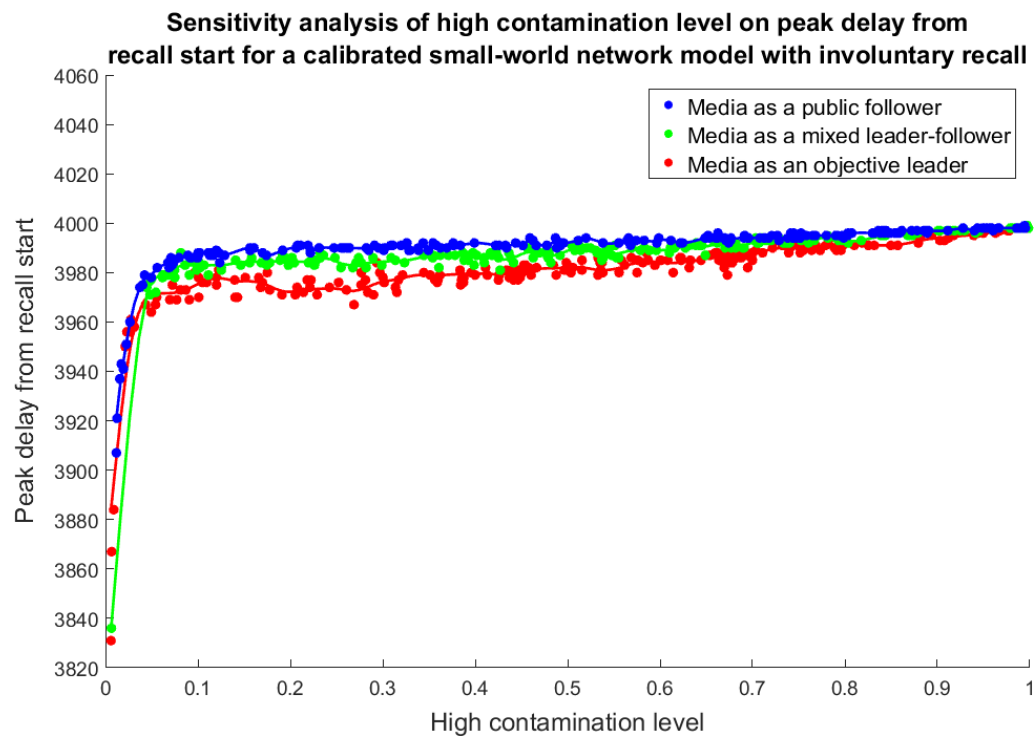Figure 7.18 Sensitivity analysis of high contamination level on peak delay from recall start for a calibrated small-world network model with involuntary recall

## 7.1.3 Conclusion to sensitivity analysis

The correlations between input parameters and outcome variables are summarised in Table 7.8. Mean risk amplification over crisis and peak risk amplification have similar patterns of relationships with independent variables. They have a perfect positive linear correlation with both maximum initial condition and maximum recreancy variation in the context of involuntary recall and a curvilinear relationship with high contamination level and contamination end period. Peak delay from crisis start and peak delay from recall start also have similar dependence on input parameters. They are a piecewise linear function of maximum initial condition and have a curvilinear relationship with high contamination level. Besides, they are perfectly positively related to contamination end period and moderately related to maximum recreancy variation (in the context of involuntary recall). All four outcome variables are insensitive to the social network parameters including number of neighbours and rewiring probability, low contamination level, maximum risk perception threshold, and maximum recreancy variation (in the context of voluntary recall). As a consequence, maximum initial condition $I$, high contamination level $C_{high}(t)$, contamination end period $T_{end}$, and maximum recreancy variation $H$ are the most significant parameters in the model.

Table 7.8 Summary of correlations between input parameters and outcome variables

| Input parameter | Outcome variable | | | |
|---|---|---|---|---|
| | Mean risk amplification over crisis $\mu_m$ | Peak risk amplification $\mu_p$ | Peak delay from crisis start $\varphi_c$ | Peak delay from recall start $\varphi_r$ |
| Maximum initial condition $I$ (voluntary recall) | Perfect positive linear | Curvilinear | Piecewise linear | Piecewise linear |
| Maximum initial condition $I$ (involuntary recall) | | Perfect positive linear | | |
| Number of neighbours $K$ | No relationship | No relationship | No relationship | No relationship |
| Rewiring probability $P$ | No relationship | No relationship | No relationship | No relationship |
| Low contamination level $C_{low}(t)$ | No relationship | No relationship | No relationship | No relationship |
| High contamination level $C_{high}(t)$ | Curvilinear | Curvilinear | Curvilinear | Curvilinear |
| Contamination end period $T_{end}$ | Curvilinear | Curvilinear | Perfect positive linear | Perfect positive linear |
| Maximum perception | No | No | No | No |

| threshold $S$ | relationship | relationship | relationship | relationship |
|---|---|---|---|---|
| Maximum recreancy variation $H$ (voluntary recall) | No relationship | No relationship | No relationship | No relationship |
| Maximum recreancy variation $H$ (involuntary recall) | Perfect positive linear | Perfect positive linear | Moderate positive linear | Moderate positive linear |

Some conclusions can be drawn from sensitivity analysis as a whole. First, compared with a voluntary recall, an involuntary recall produces a relatively higher degree of mean risk amplification over crisis and peak risk amplification. In the model, an involuntary recall can affect risk perception directly through product recall information and indirectly through recreancy. Both effects serve to intensify public perceptions of risk. In the real world, public perception of a company can be shaped by perceived corporate social responsibility (De Matos and Rossi, 2007; Jung, 2009; Magno, 2012; Souiden and Pons, 2009). An involuntary recall demonstrates that the involved company is reluctant to accept total responsibility in relation to the contamination, and that the company is not concerned with the health and safety of its consumers. Consumers' attitudes towards the company will then deteriorate, causing an increase of recreancy belief in the company that contributes to exaggerated risk responses.

Second, the objectivity of media coverage appears to be inversely related to model outputs. A media that simply follows public opinion is associated more strongly with higher mean risk amplification over crisis, higher peak risk amplification, and longer delay of peak risk amplification than one that delivers an accurate depiction of risk. When the media broadcasts public risk belief, it is communicating a more varied, mostly heightened risk. Moreover, risk communicated by such a media can spawn more enhanced ripple effects that are, in turn, perceived by the public and exert wider impacts on social response. The impacts will set back the time when risk amplification peaks and thereby increase the delay between peak risk amplification and the start of crisis or recall.

# 7.2 Model validity

## 7.2.1 Brief literature review on agent model validation

Empirical validation has recently become a major topic of concern and a central challenge in agent-based modelling field. It involves examining the extent to which the output traces produced by a particular model is an accurate representation of the real-world system being modelled. Validation is essential to recognize agent-based models as a useful scientific method of studying the aggregate response of the system. Agent-based models generally

require two stages of validation before reliable conclusions can be drawn: micro, the validation of agent behaviour at the decision-making level, and macro, the validation of aggregate behaviour emerging through interactions of multiple agents (Midgley et al., 2007; Moss and Edmonds, 2005). Midgley et al. (2007) highlight that 'the assurance, that is, the verification and validation, of agent-based models is difficult, because of the heterogeneity of agents, and the possibility of the emergence of new patterns of macro behaviour as a result of the interactions of these agents at the micro-level'. Without validation an agent-based model cannot be deemed representative of anything real. One of the core issues that result in lack of robustness in agent-based modelling is the problematic relationship between agent-based models and empirical data (Windrum et al., 2007).

## *Micro-validation*

In general, agent models are validated at the micro-level by means of model parameterization and model building. *Model parameterization* is done by referring to data on agent behaviour, decision rules, and interactions. Some modellers consult *literature* of the same field of study to select parameter values and ranges for the intended purpose of their models (Amini et al., 2012; Bulleit and Drewek, 2011). Likewise, Rivkin and Siggelkow (2003) derived five features of formal organizational design (limits on managerial ability, vertical hierarchy, incentives, decomposition, and underlying pattern of decision interaction) from qualitative literature, and used agent-based simulation to model organizational design and search. This approach allows researchers to fully explore parameters that can be incorporated in the model, distinguishing their work from prior models that have investigated only some parameters.

In addition, adoption of *empirical and published data* serves as another important approach for model parameterization. In an agent-based model of water distribution contamination events (Zechman, 2011), the author compromised reported results in a set of studies to assign a conservative value to the rate of consumer's compliance with boil water orders. In another very different study, Zhao and Ma (2016) presented an agent-based model of the diffusion of AFVs (alternative fuel vehicles). Based on a survey of traditional and electric vehicles in the market, they estimated the economic and technological details of traditional vehicles and AFVs in the model. With the aid of the statistical archives maintained by the Bank of Italy, Arciero et al. (2009) extracted a set of summary statistics to calibrate the model for simulating a real-time gross settlement system. To parameterize the agent-based modelling of the relationship between water and public health in two villages in South Africa, Demarest et al. (2013) gathered empirical data from a variety of sources including a comprehensive household census in 2009, a willingness-to-pay survey for a ceramic filter scoping study, and a year-long quality monitoring of water from the water sources and households. Rand et al.

(2015) collected datasets from Twitter to calibrate an agent-based model of urgent diffusion dynamics on social networks.

Some studies have achieved a certain level of micro-validation through *model building*. This involves structuring and translating quantitative or qualitative data into the models. The main methods used include observation, survey, interview, and so on. Dubois et al. (2013) put forward an agent-based model of a specific RPG (role playing game) named CauxOpération to grasp possible changes in participants' attitudes and to understand how game settings affect outcomes. They asked participants of CauxOpération to fill out a questionnaire on attitude changes, and then determined the main interactions between participants to be modelled, i.e. negotiations between two individuals. Leykum et al. (2012) conducted an in-depth observation to explore the impacts of sensemaking and improvising behaviours on physician teams and patient outcomes. They found out the differences between physician teams in terms of sensemaking and improvising, and how the differences were associated with patient outcomes, and then used these observations as the basis for the agent-based model. To model the attractiveness of industrial estates to firms (Fonseca et al., 2015), a survey was addressed to municipal services to collect information about the location, the characteristics, and the future plan of each industrial estate, and the Integrated Business Accounts System was compiled to gain information about the firms. The data enabled the model to replicate the conditions of the territory in light of firms and industrial estates. In the process of building an agent-based model of artificial labour market (Chaturvedi et al., 2005), agent classes, attributes, and behaviour, market variables, and market performance measures were specified using data from the real system, i.e. military recruit market for the US Army. To construct an agent-based model of agricultural land-use decision-making, Millington et al. (2008) carried out five semi-structured interviews with local stakeholders in a Mediterranean Basin. Reponses obtained from the interviews were used to determine the agricultural land-use decision-making process of local stakeholders and the types of farmer agents (traditional agent and commercial agent).

Unlike studies described above, some other studies adopted uncommon approaches, such as *ethnography* and *agent operationalization*, to gather empirically grounded data for agent model construction. For example, Ghorbani et al. (2015) used ethnography to guide the process of data collection. They first undertook semi-structured interviews with open-ended questions to cover all information required for model construction, and then conducted field observation to identify the properties of agents and physical components addressed in the interviews. Knoeri et al. (2014) set up an agent-based model of the Swiss recycled construction material market based on data obtained using agent operationalization approach, which, unfortunately, was not depicted in detail in the study.

## *Macro-validation*

There have been relatively few models that achieve validation at the macro-level. Chattoe-Brown (2014) points out that 'models that are validated and calibrated on real data remain in a significant minority'. A few studies have conducted a *case study* to demonstrate whether the model output has sufficient accuracy for insights from the real-world system over a specific domain (Dawson et al., 2011; Ferreira and Borenstein, 2011; Veit et al., 2006). This approach applies the agent-based model to the real-world system and evaluates the fit between observations from the real world and model outcome to determine the capability of the proposed model in capturing emergent features of the system being studied. Take Ferreira and Borenstein (2011) for example, they developed a normative agent-based model for supply chain planning and performed simulation experiments on biodiesel supply chain in Brazil. The results showed that the model was able to deliver all aspects related to biodiesel supply chain and provided insights into the raw material supply of a biodiesel plant in Brazil.

Another approach to operationally validating the model is *comparison of model output with expert knowledge, artificial situation, and results from literature*. The model is considered valid if the model's input-output relationship is reasonable from the point of view of individuals who are knowledgeable about the system, or model outcome is comparable to that from the real system or the literature. Particularly, there have been face validation in which the results of simulating new product diffusion were shown to experts for assessment (Günther et al., 2011), event validation in which agent-based emergency evacuation simulation with disabled individuals was compared to a physical situation with similar parameter settings (Christensen and Sasaki, 2008), and comparison of some outcome variables (i.e. congestive heart failure related hospitalization rate and mortality rate) of an agent-based modelling of accountable care organizations with values reported in the literature (Liu and Wu, 2016), to determine whether the model behaves in a reasonable way. Onggo and Karatas (2016) proposed a verification & validation (V&V) technique called Test-Driven Simulation Modelling (TDSM). TDSM validates a simulation model using a number of validation cases, and each case is implemented as a unit test. Each unit test compares model output with empirical data, analytical models, or theories. The application of this technique in maritime search operations shows that it is especially useful in the verification and validation of agent-based models.

In addition, there have been a number of studies that macro-validate the models using *quantitative measures*. Particularly, sensitivity analysis is considered as an instrument to partially validating the model by means of exploring the sensitivity of model outcome to parameter uncertainties quantitatively. It usually examines the effect of one parameter while all other parameters are held constant at their base values. This can be seen in a number of

studies, such as Grow et al. (2015), Kimbrough and Murphy (2013), Liu and Wu (2016), Millington et al. (2014), Nagarajan et al. (2012), and Okada (2011). The drawback of this method is that it does not consider interactions between parameters. Global sensitivity analysis approach, by contrast, is able to account for such interactions and applicable for nonlinear models. For example, Fonoberova et al. (2013) presented variance-based and derivative-based global sensitivity measures and demonstrated the techniques on an agent-based model of civil violence. Another quantitative measure is hypothesis test. Schuhmacher et al. (2014) used an agent-based model to simulate adolescents' risk behaviours during adolescence. On the basis of findings reported in the area of adolescence development, they proposed different hypotheses on qualitative properties of adolescent development, and chose a particular method (i.e. clustering coefficient, Moran "I" spatial autocorrelation statistic, and agglomerative hierarchical cluster analysis) for each hypothesis testing to evaluate the validity of the model.

Some studies validate the agent-based models at both the micro and macro-level. Validation approaches employed in these studies are generally combinations of the approaches discussed above. For example, model construction based on relevant theories including mixed land-use, urban mobility, and societal tolerance, sensitivity tests of the single most crucial outcome to independent variables, and comparison of model outcome with qualitative insights from real-world cities such as Berlin and Paris (Malik et al., 2015); model calibration based on experimentally developed theories regarding well-being and data from the UN Refugee Agency, sensitivity analysis, along with comparison of simulation results with those of a system dynamics model on health care in a refugee camp (Anderson et al., 2007); model building based on data from interviews, domain experts, confidential reports, various management systems, and industry statistics, and macro-validation attained through expert assessment (Sauvageau and Frayret, 2015); model calibration using micro-population data of Gwacheon City from Micro Data Service System in Korea, time-use data on city population, and geographic information data on city environment, and comparison of model outputs with survey data on Gwacheon (Lee et al., 2015); model parameterization through an empirical survey in Kanazawa City of Japan, sensitivity tests of model behaviour, together with comparison of simulation results with real data for Kanazawa City (Ma et al., 2013); model construction based on qualitative data from commercial expert review websites of computers and quantitative data from a questionnaire survey on netbook products, and sensitivity analysis (Lee et al., 2013); extraction of model elements from the literature, and partial comparison of dynamics of social risk responses with evidence found in the literature (Busby et al., 2016); model calibration by survey data from the Tourism Association of Isabela and data retrieved from the 2011 Galapagos National Park statistics and the Galapagos Tourism Monitoring Center report, and macro-validation by comparing model outcome with

data sets from the Galapagos National Park and the Galapagos Tourism Monitoring Center (Pizzitutti et al., 2014); and calibrating the model with micro data from the Beijing resale housing market survey, and exploring the impacts of input parameters on model outputs quantitatively using sensitivity analysis (Zhang and Li, 2014). These studies have achieved a relatively high consistency between model simulation results and corresponding real-world system.

Occasional studies have performed extensive tests to validate the model. Stummer et al. (2015) carried out a variety of tests to inspect the validity of an agent-based model dealing with innovation diffusion of repeat purchase products. They checked for conceptual validity through well-established theory of innovation diffusion, parameterized the model using data from various sources including survey, expert interviews, Austrian census, previous studies, and OpenStreetMap, turned to an energy market expert for evaluation of diffusion rates and market shares, and compared simulation results with the aggregate Bass model to macro-validate the model. Similarly, Jiang et al. (2016) examined innovation diffusion of multiple brands using an agent-based model. Validation of assumptions underlying the model was achieved through the solid grounding in theories of innovation diffusion and scale-free network and other established theories. Model parameterization was attained by examining empirical and secondary data, and agent decisions were validated by analysing individual behaviour data from system logs. The authors used the case of online refrigerator market in China to macro-validate the model. The simulation results were found the same as the real data in terms of the rank of the six brands' market share and the mean of each brand's market share.

## *Summary of validation techniques*

Based on the brief literature review, Table 7.9 summarises the techniques indicated for agent-based model validation. Validation techniques consist of non-statistical validation techniques and statistical validation techniques. According to studies already surveyed, non-statistical validation techniques cover a great diversity of methods including literature reference, theory basis, observation, interview, expert assessment, case study, qualitative comparison, data extraction, and so forth, while statistical validation techniques only involve sensitivity analysis, hypothesis test, and survey. It appears that most of the models that are partly validated employ non-statistical techniques, and that the rest employ statistical techniques or a combination of non-statistical and statistical techniques. This situation may result in part from 'difficulties in capturing statistics from the ABM simulation and the system being challenging to analyse due to nonlinear output' (Heath et al., 2009).

Table 7.9 Agent model validation techniques in the literature

| Technique type | Method | Source |
|---|---|---|
| Non-statistical validation technique | Literature reference | Relevant literature |
| | Theory basis | Well-established theories |
| | Observation | Questionnaire |
| | Interview | Interviewee opinions |
| | Expert assessment | Expert opinions |
| | Ethnography | Interview, field observation |
| | Agent operationalization | Agents |
| | Data extraction | Interview, survey, statistical archives, population census, Twitter, domain experts, confidential reports, industry statistics, management systems |
| | Case study | The real-world system |
| | Qualitative comparison | Real data, survey data, evidence from literature, qualitative insights from reality, results of a system dynamics model, results of a system with similar parameter settings |
| Statistical validation technique | Sensitivity analysis | Model input parameters and outputs |
| | Hypothesis test | Qualitative properties of agents |
| | Survey | Questionnaire |

## 7.2.2 Validity of the recall model

Validation of ABMS is a challenging task, since many parameters and technical issues are involved (Fagiolo et al., 2007; Sargent, 2013). In the context of risk amplification, difficulties arise from measuring objective risk level, collecting individual-level data on risk perceptions, and tracking the development of collective risk responses. Nonetheless, micro-validation and partial macro-validation have been performed to test the proposed model. In this section micro-validity is concerned with the process of model building and calibration, and macro-validity involves comparison of model outcome with time series of risk perceptions in empirical studies, secondary data, and outcomes of other models seen in the literature as well as sensitivity analysis.

### *Micro-validation*

The model was micro-validated in terms of model building and model calibration. Figure 7.19 illustrates the general process by which micro-validation was achieved. With respect to model building, the formulation of conceptual model (shown as Figure 5.2) has been grounded in the social amplification of risk framework (SARF) (Kasperson et al., 1988), theory on product

recall, and social network (Watts and Strogatz, 1998). Part of the work on which model elements were based is given in Table 7.10. The model incorporates two essential processes suggested in the literature: event discovery and recreancy, which were derived from theoretical and empirical studies on social risk amplification and product recall. Specifically, of the subcomponents within the event discovery process, direct experience and social interaction were drawn from the literature on risk amplification. Product recall information within the process of event discovery, together with recall timing and recall voluntariness that influence the recreancy process, was based on work concerning public response to a product recall event. Media communication, which has been widely studied in both fields of risk amplification and product recall, was integrated with the impacts of these two processes to shape social experience of risk.
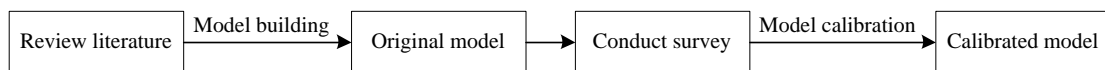


Figure 7.19 Micro-validating process of the recall model

Table 7.10 Evidence for micro-validation of model elements

| Element | Decision rule or model assumption | Validating evidence | Evidence type | Context |
|---------|-----------------------------------|---------------------|---------------|---------|
| Model dimension | Non-linearity in social amplification processes | Burns and Slovic (2007) | Model | Terrorism |
| | | Busby et al. (2016) | Model | Multiple |
| | | Busby and Onggo (2013) | Empirical, model | Zoonotic diseases |
| | | Bleda and Shackley (2012) | Empirical, model | BSE |
| | Heterogeneity of individual risk perceivers | Slovic et al. (1982) | General synthesis | All |
| | | Marris et al. (1997) | Empirical | Multiple |
| | Social networks have small world properties | Watts and Strogatz (1998) | General synthesis | Multiple |
| | | Barabási and Albert (1999) | General synthesis | Multiple |
| Event discovery | Direct experience reinforces public concern about risks | Kasperson and Kasperson (1996) | General synthesis | Wildfire risk |
| | | Loewenstein and Mather (1990) | General synthesis | Multiple |
| | | Smith et al. (2013) | Empirical | Wildfire risk |
| | | Rogers (1997) | Empirical | Hazardous waste and energy production |
| | Social interaction is strongly associated with risk perception | Binder et al. (2011) | Empirical | A biological research facility |
| | | Smith et al. (2013) | Empirical | Wildfire risk |
| | | Kasperson (2012) | General synthesis | Multiple |
| | Product recall information acts as a risk amplifier | De Matos and Rossi (2007) | Empirical | Car recall |
| | | Desai and Patel (2014) | Empirical | Nokia BL-5C battery recall |
| | | Freedman et al. (2012) | Empirical | 2007 toy recalls |
| Recreancy | Recreancy is an important contribution to risk amplification | Kasperson and Kasperson (1996) | General synthesis | Multiple |
| | | Freudenburg (2003) | General synthesis | Multiple |
| | | Petts and Niemeyer (2004) | Empirical | MMR |
| | | Stanciugelu (2013) | Empirical | Earthquake |
| | | Boyd and Jardine (2011) | Empirical | BSE |

| | Recall timing affects consumers' attitude toward the producer | Magno (2012) <br> Standop (2006) | Empirical <br> Empirical | Laptop recall <br> Bicycle recall |
|---|---|---|---|---|
| | Recall voluntariness accounts for consumers' recreancy perception in the producer | Laufer and Coombs (2006) <br> Souiden and Pons (2009) <br> Vassilikopoulou et al. (2009a) | General synthesis <br> Empirical <br> Empirical | All <br> Automobile recall <br> Mobile phone crisis |
| Media | Media serves as a critical amplification station | Lewis and Tyshenko (2009) <br> Renn et al. (1992) <br> Yeo et al. (2014) <br> Chung (2011) <br> Frewer et al. (2002) <br> Burns et al. (1993) | Empirical <br> Empirical <br> Empirical <br> Empirical <br> Empirical <br> Empirical, model | BSE <br> Multiple <br> Nuclear power <br> Tunnel construction <br> Genetically modified foods <br> Multiple |
| | Media plays multiple roles in risk debates | Onggo et al. (2014) <br> Leschine (2002) <br> Bakir (2005) | Model <br> Empirical <br> Empirical | Multiple <br> Oil spills <br> Deep-sea disposal of an oil rig |

Selecting model elements from prior work not only provides some micro-validation, it also helps synthesize previous studies and gain a more comprehensive insight into the formation of risk perception in a product recall crisis. It goes beyond prior models that have examined only a subset of these elements, contributing to a more complex view of social risk amplification. However, elements incorporated into the model are extracted from various studies in quite different social contexts from that of this study (i.e. risk associated with product contamination). Another disadvantage is that, it is almost impossible to find clear evidence in the literature that can help determine the agents' decision rules or set the values of model parameters, since no research has investigated these elements as distinct elements.

Once the model had been constructed logically, based on this literature, it was partially calibrated by a public survey. The survey aimed to determine the information sources that individuals consult when forming their risk perceptions and the relative importance that they give to different pairs of information sources when a liquid milk contamination incident occurs in China. As described in Section 6.2.2, all comparisons were made relative to the same baseline, i.e. social interaction, except for the comparison between recall timing and recall voluntariness. And for each pair of comparison, both forward comparison and reverse comparison were used.

The manipulation of how a question is framed, in this case how two types of information sources in the same question are ordered, affects what becomes a reference point (the one encountered first) for comparison in the decision process and is associated with an attentional effect that focuses respondents' attention on the reference point (Levin et al., 1998). Displaying each question only in the form of forward comparison may lead to a situation in which respondents pay less attention to *other people's perceptions* than the one compared

with it. Applying both forward and reverse comparisons is based on the notion that posing questions in different ways can encourage respondents to think about or defend their choices before making a final decision. Empirical findings in the literature have indicated that the distortion of choice caused by the framing effects can be diminished or eliminated if one engages in effortful thought (Smith and Levin, 1996; Tversky and Kahneman, 1986). This means that elaboration of messages and justification of decisions can suppress the framing effects. In addition, as explained in Section 6.7, a test was conducted to look at the consistency between forward and reverse sense. The results showed that there was little polarization of opinions based on different ways of comparisons in each case.

Figure 7.20 briefly summarises the process by which the model was calibrated using data drawn from the survey. In the first treatment of survey data, reverse comparisons were transformed to forward comparisons by converting recoded values of the former into those of the latter, such that in each case the data were responses to forward comparison. In the second treatment, recoded values were denoted by ratios according to Table 6.5 in Section 6.6.2. The weights of information sources were obtained according to the relationships between weights and questionnaire items shown in Section 6.7. Lastly, the dataset for each weight was fitted into a beta distribution, such that all agents follow the same updating rule but each agent adopts a unique set of parameter values. It is important to note, however, this represents only a partial calibration of the model, as there are model parameters such as the objective risk level, the threshold in risk perception, and the recreancy variation which are not examined by the survey. Each agent is endowed with a threshold in risk perception sampled from $[0, S)$ and a variation in recreancy sampled from $[0, H)$ according to a uniform distribution. Further empirical work will be needed to calibrate these values.
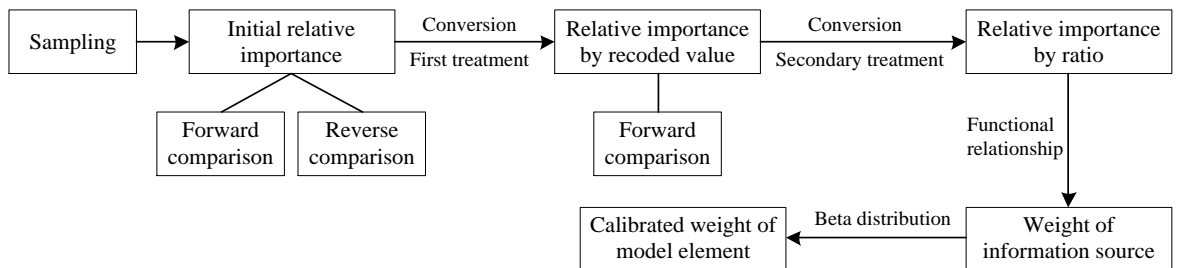


Figure 7.20 Model calibration process by survey data

It is also important to recognise that parameters like the objective risk level are specific to every case being modelled. And in practice it may be hard to know what the objective risk level is, since expert risk assessments are often in disagreement. In the Sanlu incident described in Chapter 3, there were a total of around 300,000 victims, but there was no report

of number of new cases over time – times series of problem levels were unavailable. The perception threshold (if the risk perception is above this threshold but the firm has not announced a recall then recreancy is increased) and recreancy variation (if the firm makes a voluntary or an involuntary recall then recreancy is decreased or increased by a certain amount) may or may not be stable across different incidents. This requires empirical work to determine. The main point is that the attempt to calibrate the model is undertaken with a specific context in mind, and this exercise does not by itself reveal how the calibration will vary as the context varies.

## Macro-validation

There are four bases for macro-validation: comparing model outcomes with primary empirical data, comparing them with secondary data, comparing them with the outcomes of other models in the literature, and sensitivity analysis.

### Use of primary empirical data

The first basis of macro-validation is comparison of the model output with empirical data. This kind of macro-validation of the recall model is difficult, and was *not* achieved in this study, because it is very hard to collect empirical time series of public risk perception around a specific recall crisis unless risk responses or risk related behaviour are observable before and during and after the recall event. Besides, this process is also costly and time consuming. One weaker approach for performing macro-validity is to compare model output behaviour to observations of similar studies using graphical displays (Sargent, 1996). Loewenstein and Mather (1990) examined time series data of public concern in relation to nine different risk issues. Table 7.11 summarises the measures of risk perception they employed and the qualitative patterns of these time series, based on a modification of a similar table in Busby et al. (2016). Some cases display extreme fluctuations of public concern that greatly deviates from the level of objective risk, which are considered as a result of occurrence of panic that underlies the dynamic response to risks. It is also observed that public risk perception is not immediately fully evoked by an increase in the objective severity of underlying problems but gradually grows towards a peak. Of these risk issues, only drink driving displays a similar time series trace to the recall model: risk perception grows progressively towards an exogenous peak and declines immediately.

Table 7.11 Risk perception patterns of issues analysed by Loewenstein and Mather (1990)

| Risk issue | Proxy measure of public concern | Qualitative pattern of time series |
|---|---|---|
| AIDS | Frequency of national news articles | Double peak with multiple fluctuations<br>Objective incidence monotonically increasing |
| Crime | Percent of respondents afraid to walk at night by general social survey | Single peak with non-periodic non-monotonic movements<br>Objective incidence fairly similar with smoother trend |
| Drink driving | Difference between number of drink driving groups founded and disbanded | Single peak with non-periodic non-monotonic movements<br>Objective incidence fairly similar with smoother trend and leading by about 1 year |
| Herpes | Frequency of national news articles | Single peak with non-periodic non-monotonic movements<br>Objective incidence fairly similar without significant peak and lagging by about 1 month |
| Inflation | Percent of respondents citing inflation as the most important issue by opinion poll | Double peak with non-periodic non-monotonic movements<br>Objective incidence fairly similar |
| Unemployment | Percent of respondents citing unemployment as the most important issue by opinion poll | Multiple peaks<br>Objective incidence fairly similar |
| Polio | Frequency of New York Times news articles | Multiple peaks<br>Objective incidence moving in opposite direction in some periods |
| Teenage suicide | Frequency of national news articles | Single peak with extreme high amplitude<br>Objective incidence similar with small monotonic movements |
| Teenage illegitimacy | Frequency of New York Times news articles | Single peak with multiple small fluctuations<br>Objective incidence slightly monotonic rising |

Generally, the action of collecting time series data on risk perception should be taken from the initial onset of a risk issue and in a real-time manner, so that the dynamic change in risk perception over a long period of time can be observed and more insight into collective response to risks can be obtained. Some empirical evidence of this kind is available, as shown in Table 7.12.

Table 7.12 Comparison evidence for macro-validation

| Evidence | Evidence type | Data source | Context | Comparison |
|---|---|---|---|---|
| Lau et al. (2003) | Empirical | Time series | SARS | Trend and magnitude of risk perception |
| Ibuka et al. (2010) | Empirical | Time series | H1N1 influenza | Trend of risk perception |
| Busby and Onggo (2013) | Empirical, model | Interviews, focus groups | Zoonotic disease | Trend and magnitude of risk perception |
| Busby et al. (2016) | Model | None | Multiple | Trend of risk perception |
| Bleda and Shackley | Empirical, | News articles, | BSE | Trend of risk perception |

| (2012) | model | secondary time series | | |
|---|---|---|---|---|
| Burns and Slovic (2007) | Model | Secondary survey results | Terrorism | Trend and magnitude of risk perception |
| Onggo et al. (2014) | Model | None | Multiple | Magnitude of media communication |

The study proposed by Lau et al. (2003) showed the evolution of risk perception alongside reported cases during the outbreak of SARS. Figure 7.21 is based on Lau et al.'s (2003) data and illustrates the proportion of newly reported cases to the Hong Kong population and the percentage of respondents in the surveys perceiving a high risk of being infected with SARS. The use of this data to help validate a simulation model can also be found in Busby and Onggo (2013). A comparison of simulation results of the recall model (Figure 7.22 and Figure 7.23) with this empirical record shows some correspondence: there is a rapid growth in public risk perception followed by an immediate decline, with risk perception being exaggerated in most periods. There is also some difference between them: the trace of risk perception from Lau et al. (2003) closely followed the number of reported cases, while the one from the recall model is quite different from the contamination level. This is because real data can produce more realistic time series trace than the model that is established based on simplified assumptions. Similarly, Ibuka et al. (2010) examined the dynamics of risk perceptions of H1N1 influenza using a public survey carried out at the initial stage of outbreak. It was found that perceived risk of H1N1 infection increased over time with some fluctuations of low amplitude. These fluctuations are absent in the recall model, probably because relevant dynamic effects are not represented in the model – for example the unpredictable effects of disease spreading.
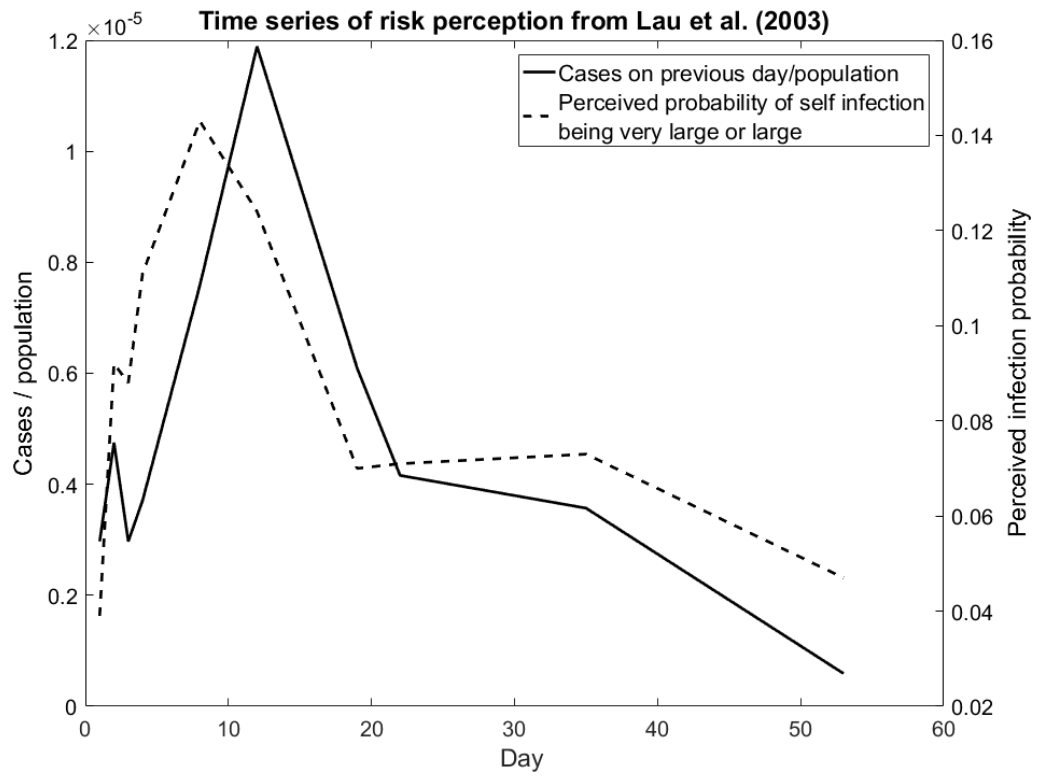
Figure 7.21 Time series of risk perception from Lau et al. (2003)
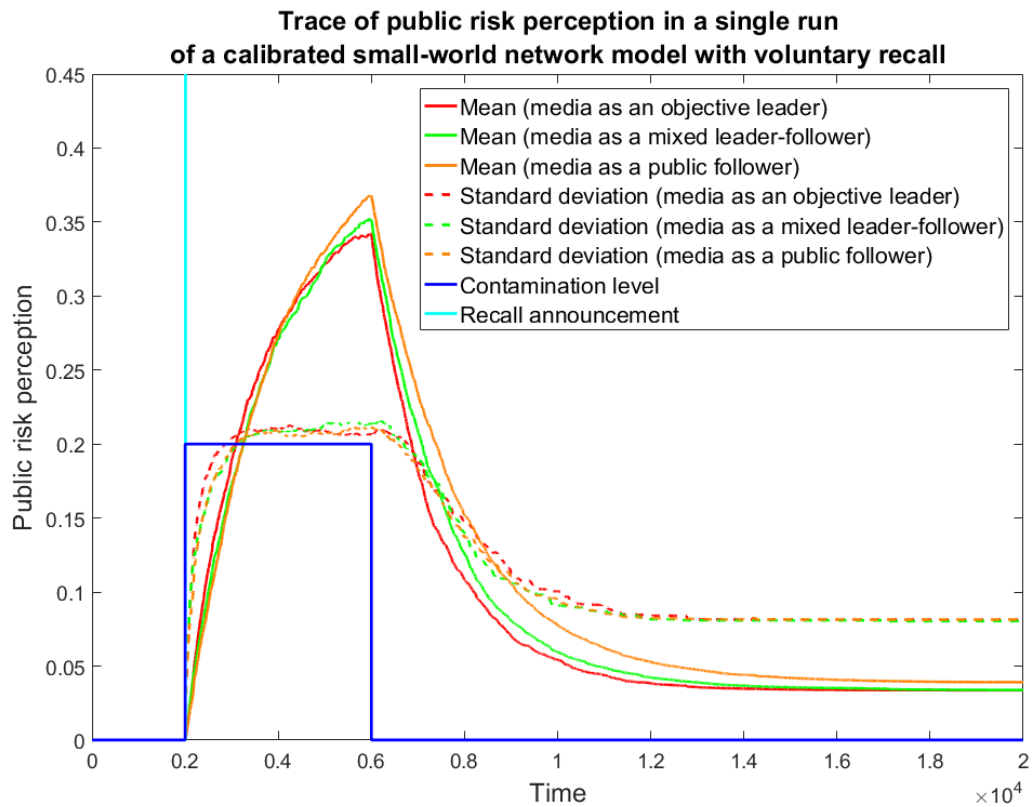


Figure 7.22 Trace of public risk perception in a single run of a calibrated small-world network model with voluntary recall ( $a(t=2008)=1$ , $v(t)=1$ )
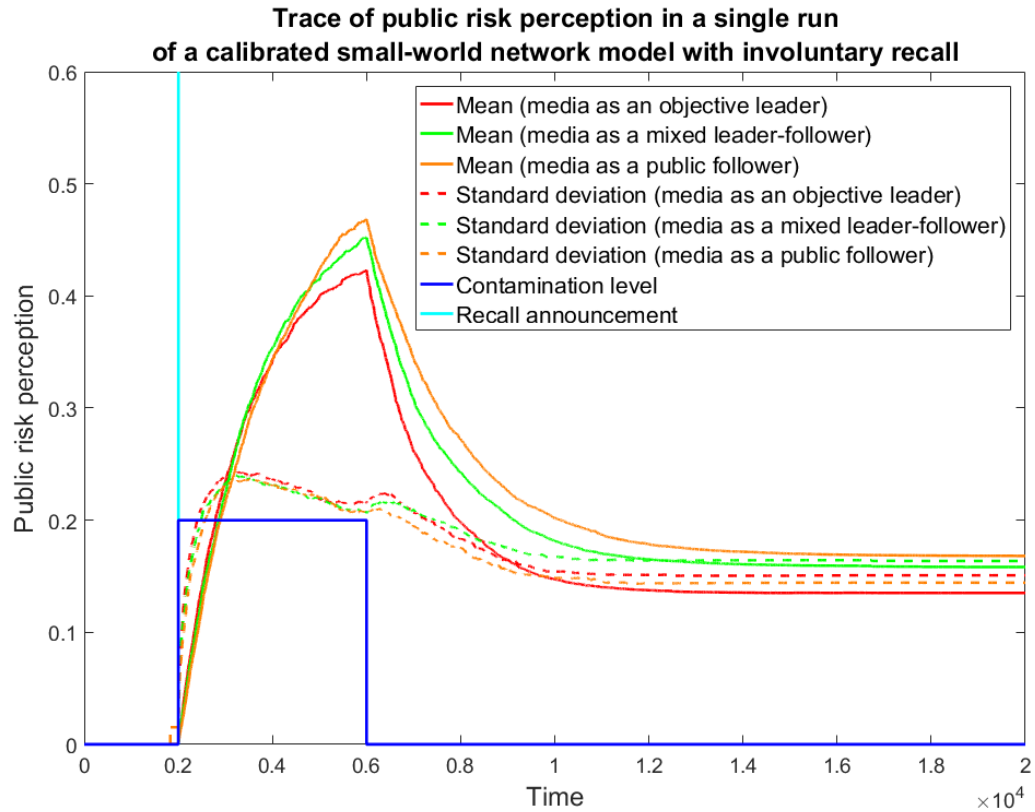
Figure 7.23 Trace of public risk perception in a single run of a calibrated small-world network model with involuntary recall ( $a(t=2003)=1$, $v(t)=0$ )

Ideally, macro-validation of the recall model in this study would consist of data collection on a time series of risk amplification, data analysis, and comparison of the model output to empirical data. Data collection mainly involves survey design and sampling. The population to be sampled is consumers of the product in question. This population should be surveyed before and during and after a crisis, so a number of (e.g. 10 or 15) surveys will be carried out since the start of the crisis, and each round of survey will be completed in one day. Questions included in the survey should differ depending on the evolution of the crisis – questions regarding product recall will be added when the survey is conducted during the crisis. In regard to data analysis, responses for each round of survey will be averaged across questions and across respondents to yield an aggregate value for risk perception. Lastly, make a comparison to check whether the projections of the recall model are close to public perceptions of risk based on time series data. A critical problem is that the objective risk may be unobservable in reality. This indicates that what might prevent successful macro-validation is not being able to survey risk perceptions but being able to determine objective risk levels.

## Use of secondary data

Another approach to validating the model at the macro-level is to use secondary data from social media platforms and search engines, such as Google Trends. A number of studies have used Google Trends data for surveillance of epidemics and diseases such as influenza outbreaks (for example, Carneiro and Mylonakis, 2009; Kang et al., 2013; Seifter et al., 2010), or incorporated information from Google Trends to undertake forecasting such as forecasting of private consumption (Vosen and Schmidt, 2011) and forecasting of consumer purchases (Choi and Varian, 2012). But it appears that Google Trends cannot be effectively applied to monitor how individuals perceive risks over the course of a risk event or to validate the model.

First, it presents few details of a risk event and may miss some critical information regarding the development of the crisis. Take Sanlu milk scandal for example, the Google Trends graph (Figure 3.1 in Chapter 3) depicts the frequency of queries on some issues and obviously fails to cover information regarding product recall, which is usually a concern of consumers as well as an important consideration of the model.

Second, Google Trends may be not a good indicator of risk perception. It provides a time series index of the volume of searches on a particular risk event. This could be an indication of the strength of public concern, but it is unknown if it is a good measure, or can be used as a proxy, for risk perception.

Third, Google Trends data is based on a sample of web searches, with the potential of non-representative sampling bias. It only samples people who use Google to find out the risk and ignores those who cannot have access to Google or do not rely on Google for risk information.

Google Trends may be a promising instrument to extract useful search data in some cases (for example, track disease outbreak). However, it is currently not suited to detect time series of public risk perceptions.

## Use of other models

The third basis of macro-validation is comparison of the model output with the output of prior models (as shown in Table 7.12). Some models that essentially involve a social process shaping risk perception also provide a basis for comparing qualitative features of dynamic response to risks. They are not based on the context of product recall, but there is some overlap of independent and dependent variables. A system dynamics model (Busby and Onggo, 2013) exploring the idea of social amplification as an attribution with recreancy taken into account in the context of zoonotic disease outbreaks, for example, indicates that risk beliefs become polarised among different actors, and that a residue of concern exists after a crisis ends. This is very similar to the qualitative properties of the recall model in that the

standard deviation of the opinion distribution across the population is high during and after the crisis, and that public risk perception remains very high even when the contamination falls to its original, low level. Furthermore, in the recall model risk perception climbs progressively toward an exogenous peak before it decays as the crisis ceases. Similarly, a more recent agent-based modelling of mechanism of risk amplification (Busby et al., 2016) produces a qualitative pattern of risk perception characterized by a continual growth, sometimes repeated, followed by an immediate decline.

A social simulation model intended to analyse the dynamics of public perceptions of risk associated with BSE in the UK was described by Bleda and Shackley (2012). The trace of risk perception exhibits the similar pattern: a noticeable peak followed by low risk perception at the last stages of the simulation period. Burns and Slovic's (2007) system dynamics model also incorporates the role of media coverage to examine how a community may respond to a terrorist attack over a six-month period. It provides evidence that public risk perception grows very quickly but drops comparatively slowly, and that it remains at a higher level than before the crisis. Furthermore, the recall model corresponds to the agent-based model constructed by Onggo et al. (2014) in terms of the role of media in the dynamics of social response to risk: a media that follows public opinion has a more pronounced amplifying effect on public risk perception than one communicating the objective risk to the public.

*Sensitivity analysis for macro-validation*

As indicated earlier, sensitivity analysis also provides a limited kind of macro-validation. In a situation where the system being modelled is unobservable (observational data on the system is inaccessible), which is in fact the case for this study, sensitivity analysis is usually applied to evaluate model robustness and considered as an indirect approach to macro-validating the model (Frey and Patil, 2002; Sargent, 2007; Sargent, 2010). Sensitivity analysis also helps to assess the precision of the model by looking at its performance associated with changes in various parameters (Fraedrich and Goldberg, 2000).

As described in Section 7.1.2, the degree of risk amplification and the delay of peak risk amplification are sensitive to maximum initial condition, high contamination level, contamination end period, and maximum recreancy variation (in the case of involuntary recall). This model response seems reasonable and helps with potential future validation by identifying important uncertainties in the model that can be used as an aid in prioritizing accumulation of observational data in the validation process (Kleijnen, 1995; Trucano et al., 2006). The sensitivity estimates show which relationships between model parameters and outcome variables are the most important and deserve more data collection efforts, apart from

the fact that it shows what needs most managerial attention because it has the potential to cause large uncertainties in an outcome critical to an organization.

# 8 GENERAL DISCUSSION

This chapter consists of three sections shown in Figure 8.1. The first section elaborates on how the proposed model is connected with SARF, both in term of elements seen in SARF and those not dealt with in SARF. The second section deals with the contextual specificity of the model. It describes the extent to which the model is contextual and how important the modelling of context should be in the way we think about SARF. The last section focuses on how the model answers the research questions.
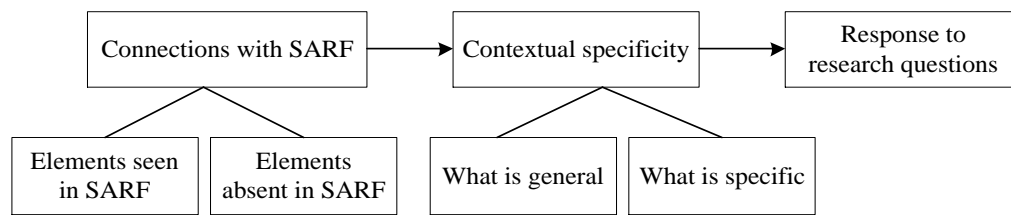


Figure 8.1 Structure of Chapter 8 General Discussion

## 8.1 Connections with SARF

The recall model is linked with SARF (Kasperson et al., 1988) in at least three aspects. *First of all*, the model takes risk amplification as a key outcome variable. A central focus in SARF is to explain the disparity often seen between expert assessment of risk and public perceptions of risk. This has also been a core issue facing decision makers in terms of risk communication (Smith and McCloskey, 1998). The purpose of risk communication has often been seen to overcome the misperception of risk among a public that either exaggerates the real level of risk, or under-estimates it. This creates a need to analyse the dynamic process of misinterpreting the risk. So a prime concern in the modelling is this disparity, which was simply captured as the gap between mean public risk perception and objective risk level at any one time. The principles that the gap between true risk and public perception is an objective quantity, and that the purpose of risk communication is to correct this, have been criticised (Rayner, 1988), but the gap between some objective quantity and a public belief remains the simplest way of stating risk amplification as an outcome.

    *Second*, the model incorporates a number of critical elements seen in SARF to investigate the underlying dynamics of how risk and risk related behaviours evolve. SARF emphasizes the role of various amplification stations (e.g. individuals, social groups, media, and so on) in conveying risk signals and in the formation of risk perception. Social processes often act to either intensify or downplay collective response to risks. Risk perception not only represents the direct consequences of a risky event but also is conceptualised as a social construction

(Burns et al., 1993; Renn et al., 1992). In this sense, the model explores the effects of direct experience, social interaction, and media on the social process of amplifying or attenuating risk. There has been no prediction about which of these elements is likely to be the most important generally, as SARF has examined their significance in the social amplification of risk in a wide range of contexts. Therefore, the model does not make any assumption of one element being more influential than another. Moreover, the model is simply a linear additive one, so each element has an independent effect on the adjustment of risk perception. Although the interactive effects that may exist between the elements are neglected, integrating them into a simple decision rule is a reasonable starting point for representing their contributions to risk amplification.

*Third*, the model explains social risk amplification as a mechanism and integrates the product recall process that is absent in SARF into the amplification process. The core of SARF is the mechanism of risk amplification (Kasperson et al., 1988), which, however, has received little emphasis in past empirical work – as was described in the Literature Survey (Chapter 2). There has been quite limited modelling of risk amplification to date, as also detailed in the Literature Survey (Chapter 2). Another point is that little attention has been given to the investigation of the role of organizational misconduct in shaping the strength of risk responses. As well as discovering the nature of a risk, individuals also make judgments about the crisis response of the involved organization to revise their perceptions of risk. The model uses a product recall process to indicate public perceptions of organizational misconduct that is combined with direct experience and social communication to explore the mechanism of social risk amplification in the context of a product contamination crisis.

## 8.1.1 Elements seen in SARF

The model incorporates a number of key factors that have been recognized in the SARF literature as prominent drivers of public risk perception, such as direct experience, social interaction, and media.

### *Direct experience*

Direct experience is simultaneously an experience of physical harm and a process by which individual actors learn about related risks (Kasperson, 2012). Yet, so far there have been few studies (for example Barnett and Breakwell, 2001) that explain direct experience as a separate driver of risk perception when examining its influence. In the agent model, direct experience is explained as a single episode that merely reflects the fact whether an activated agent has had the experience of consuming a contaminated product or not. Kasperson et al. (1988) have

pointed out that direct experience can produce an amplification effect by enabling individuals to learn about the nature and controllability of hazardous events. In this process people may change the weight given to direct experience or even the structure of the model if risk indicated by direct experience is much higher than their perceptions. Moreover, in the process individual actors create interpretations of the risk and establish their own rules of filtering and processing risk signals from indirect, or secondary, experience (Renn et al., 1992). Such a process is not considered in the agent model, because it is not expected to significantly influence model outcome.

The model is developed in the context of risk associated with product contamination, so an agent's direct experience is an experience of consuming contaminated products. The model behaviour shows that risk amplification only emerges when the contamination level is below a certain threshold, and that the magnitude of risk amplification decreases with the contamination level. The notion is that the amplifying effect of direct experience is inversely related to the gap between the objective risk and risk perception prior to the experience. This does not mean that the impact of direct experience is insignificant but that the impact cannot always elevate risk perception to an exaggerated level. There is no evidence of the effect in the SARF literature, to the author's knowledge, and this would be worth empirical exploration.

Results from the survey show that, among four information sources summarised as the 'discovery' component of the model, direct experience with liquid milk contamination receives a mean weight (28.1%) relatively higher than that of prior belief (27.1%), that of social interaction (18.7%), and that of product recall information (26.2%). A Welch ANOVA ($F(3, 603.526) = 32.768$, $p < 0.001$) shows that there is a statistically significant difference in the mean weight between the four sources of information. A Games-Howell test ($p < 0.001$) reveals that social interaction has a statistically significantly lower weight than the other three sources. However, there are no differences between these three. Although no other evidence has been found on the role of direct experience in shaping risk responses, it should be noted that the result may vary with risk events due to contextual differences. Barnett and Breakwell (2001) have empirically demonstrated that the effects of experience on risk concern are clearly differentiated with respect to whether individuals participate in the risk activities voluntarily or involuntarily: experience is closely linked with stronger concern about involuntary risk activities, while there is no association between experience and concern about voluntary risk activities. This indicates a direction for further research.

## Social interaction

The social dynamics linking interpersonal communication and risk perception have received relatively little attention in research on the social amplification of risk (for example, Binder et al., 2011; Smith et al., 2013). This model looks at whether informal social interactions amplify or attenuate risk perception of product contamination and the magnitude of such effect. It represents the informal social interaction in the form of an influence in which the activated agent consults the mean risk belief of its neighbours. Social interaction serves as an information source that sends out risk signals to an activated agent, so each agent acts as a receiver when it gets activated and as a transmitter when its neighbours are activated. The use of a similar belief updating process can also be seen in Busby et al. (2016) and Onggo et al. (2014), although with a different implementation of exactly how the updating occurs. Busby et al. (2016) modelled social interaction as a convex function of response from the perspective of availability heuristic of risk perception, and Onggo et al. (2014) treated interpersonal communication as a narrowcast process to contrast it with broadcast from media.

The traces of agent risk beliefs demonstrate that social interaction produces convergence on mean public risk perception, and that the variation in individual risk perceptions falls to a certain constant level during an initial settling period of the model. In the survey, only 21.5% of the respondents gave more importance to neighbour perceptions than their own, prior beliefs, 51.4% favoured their own beliefs, and the rest weighted these two sources equally, reflecting the inter-individual variability on this aspect. This variability is incorporated in the calibrated model. According to further experiments of the partial model (which merely considers social interaction), opinion clustering occurs when the weight of social interaction is large, as expected: risk perception tends to become homogeneous as the strength of inter-communication between neighbouring agents increases.

As described earlier, public agents in the model interact with neighbours in a small-world network (Watts and Strogatz, 1998). Findings gained from sensitivity analysis on the calibrated full model are that number of neighbours $K$ (which refers to the number of nearest neighbours each agent is connected to in initial regular lattice) has a very small effect on risk amplification, and that rewiring probability $P$ (which is the probability of reconnecting a lattice edge) has almost no impact on the degree as well as the delay of peak risk amplification. This indicates that the dynamics of social risk amplification are insensitive to the topology of the social network.

This insensitivity is not what was expected. As an increase in the number of neighbours increases the number of channels conveying information and decreasing the rewiring probability generates more shortcuts between distant agents (Watts and Strogatz, 1998), it was expected that both parameters influence the flow of information across the network and social

risk amplification accordingly. But there are some possible reasons for this unexpected insensitivity. In regard to *rewiring probability*, the sampling approach used in the sensitivity analysis may explain the result. Characteristic path length $L(P)$ (which is defined as the number of edges in the shortest path between two nodes, averaged over all pairs of nodes) drops very fast for small rewiring probabilities with an order of magnitude of -2 or less towards a relatively low level that prevails for larger rewiring probabilities (Barrat and Weigt, 2000; Watts and Strogatz, 1998). Figure 8.2 shows characteristic path length $L(P)$ for the small-world network with 1,000 nodes and a degree of 4 neighbours used in the sensitivity analysis. A base 10 logarithmic scale is used for the X axis that signifies rewiring probability $P$. On the Y axis characteristic path length $L(P)$ is the average over 500 random realizations of the rewiring process for each value of $P$ and normalized by $L(0)$. In the sensitivity analysis the rewiring probability was sampled 200 times uniformly from the range $[0,1]$, so the frequency of values below $10^{-2}$ was very low. As a result, there was little difference in the number of shortcuts among the sampled values of rewiring probability, leading to the insensitivity of risk amplification to the rewiring probability.
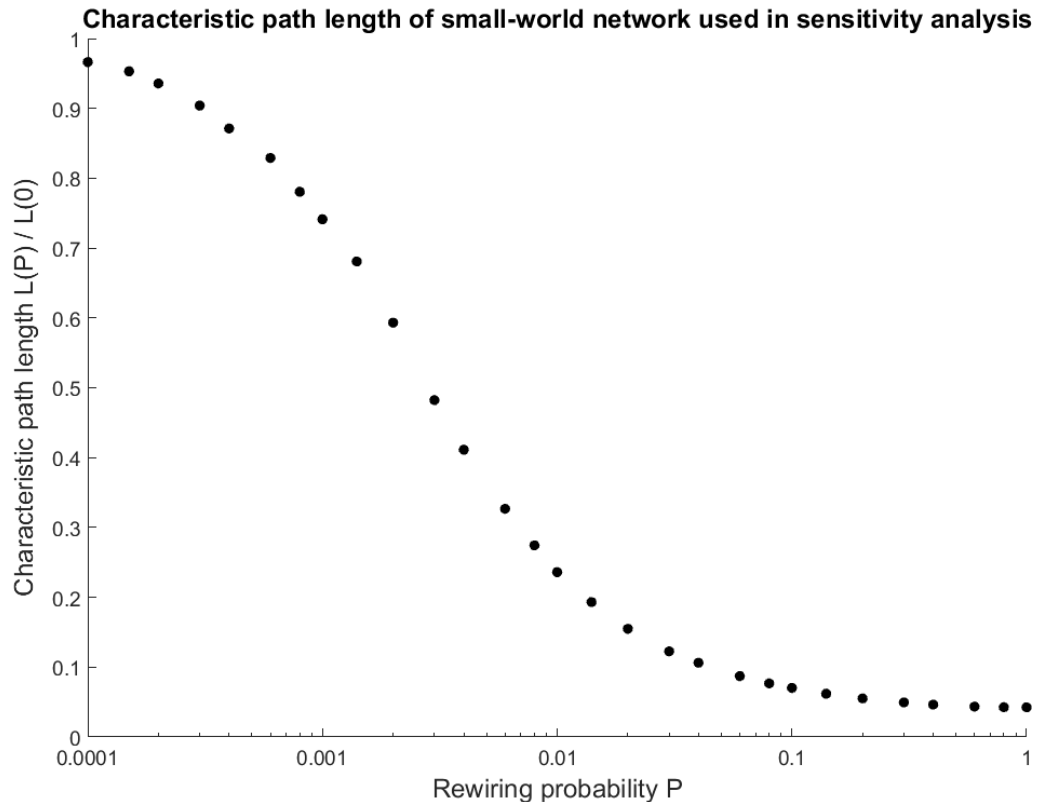


Figure 8.2 Characteristic path length for the small-world network used in sensitivity analysis

With respect to *number of neighbours*, the insensitivity is due to the reason that an increase in the link degree cannot cause the local network effect to increase significantly. When the number of neighbours increases, agents are exposed to more opinions of other people. However, as agents consults mean risk belief of their neighbours, changes in the number of neighbours cannot make much difference to agent risk perceptions. Consequently, there is little dependence of social risk amplification on the connectedness of the social network. There has been little evidence on the effect of social network parameters on risk amplification in the SARF literature. For example, Busby et al. (2016) have shown that public risk perception is insensitive to the network parameter defining the link degree distribution.

A recent agent-based model of the diffusion dynamics of competing products (Lee et al., 2013) also adopted Watts and Strogatz's (1998) small-world network. The social network was designed in quite a similar way to the network of public agents in the recall model: consumer agents make purchase decisions based on their own evaluations of product attributes and the average ratings of product attributes from their neighbours, with both being assigned a weight sampled from empirical distributions. The authors conducted sensitivity analysis with respect to the network parameters and obtained similar results: the degree of connectivity only had a marginal effect on the market shares of products, and the rewiring probability had no impact. The algorithm they used for social interaction is similar to the belief updating rule in the agent model: in Lee et al.'s (2013) model the ratings each consumer-agent gives to product attributes is the weighted average of their own judgment and evaluations from their neighbours. This may be one reason why similar results with respect to network effect are obtained. The authors said that the insensitivity to the number of neighbours were due to an effect of averaging evaluations of all neighbours as well as an exponential distribution of agent purchase time. The rewiring probability could not create a significant effect on the number of shortcuts among consumer-agents as the number of neighbours (i.e. 4) in the social network was small. The indication from the recall model and Lee et al.'s (2013) model is that the effect of social network on model outcome is not as marked as might be expected.

In addition to the insensitivity just described, the model of a small-world network in this study produces only one convergence on mean public belief. The exogenous peak emerges around the time when the contamination level drops to its original level, with no fluctuations occurring anywhere else. In contrast, Busby et al.'s (2016) agent model of a scale-free network generates convergence on two different levels of risk belief before and after the change of objective risk, with risk belief fluctuating frequently. It can be seen from the comparison that different types of social networks display quite different patterns of risk perception, although these two models are based on different structures and assumptions.

## *Media*

As explained in the Literature Survey (Chapter 2), news media can play multiple, sometimes controversial, roles in the debate about risks: they may explicitly amplify a risk, or attenuate a risk, or depict a risk in an unbiased way. In the agent model the media has a different mechanism of shaping risk perception from social interaction: it directly broadcasts risk messages to the entire population as one information source, whereas social interaction contributes to the amplifying process through one-to-many agent communication.

In the recall model, in order to explore how the magnitude of risk amplification differs in terms of the role that the media is playing, media communication is operationalized in terms of three different possible roles (Onggo et al., 2014): an objective leader communicating the objective risk, a mixed leader-follower broadcasting the mean of public risk perception and the objective risk, and a public follower broadcasting public risk perception. The level of public concern does not necessarily accord with the intensity of media coverage. Lay persons are increasingly active in engaging in risk debates and in questioning the accuracy and reliability of media portrayal of risks (Chung, 2011; Petts et al., 2000). Based on these notions, in the model each agent assigns a different weight to media expressed risk that was sampled from a beta distribution that the survey data was fitted with.

The model exhibits the same qualitative pattern of risk perception with different levels of risk amplification across the three different roles of media, both in the course of a crisis and after its resolution. A media that follows public opinion generates a relatively higher degree of risk amplification than one reporting the objective risk, with a mixed strategy being in between. In contrast, Onggo et al.'s (2014) model demonstrated almost no difference in risk amplification produced by three media roles during an outbreak and significant differences after the outbreak with a follower role intensifying risk to the largest extent. They modelled a situation in which individuals invest little trust in the media and give a much lower weight to media communicated risk than social interaction. Consequently, decision makers have to examine the role of media in risk communication when media is a primary source of information for the general public. In other words, a company having to make a decision about a product recall needs to decide which model of the media seems most realistic in order to predict the effect that reporting the recall in the media will have.

The questionnaire survey showed that respondents were attaching more importance to media coverage (a mean weight of 20.7%) than neighbour perceptions (a mean weight of 11.6%) – a statistically significant difference with $t(df = 362.198) = 9.647$ and $p < 0.001$. The public appears more sensitive to media portrayal of risk than their social network. Combined with the insight from the model just described, the survey result suggests that the role that the media plays matters in the context of a milk contamination crisis. These results

from the model and survey offer an indication of the effect of media communication on the formation of risk perception for risk managers. It is clear that attention needs to be concentrated on how the media depicts risks or risk events in order to make informed decisions, and that better communication strategies may be needed particularly when the media is a strong follower of public opinion.

The model does not consider the possibility that the media plays more than one role during the crisis. The media may switch its positions by changing the way in which it describes the risk. Take the Chinese milk scandal for example: before the scandal was extensively exposed, the media objectively reported the number of victims from melamine contaminated milk powder. However, as the scandal broke, news media were ordered by the central government to follow the official line and avoid negative reporting (Li, 2008). This added a further dimension of complexity to the contamination issue, yet it is ignored in the model. And evidently, the role of government in the process of interpreting such risk debates is also an important direction to be examined. This point is addressed in the Conclusion (Chapter 9), where possible future work is discussed.

## 8.1.2 Elements absent in SARF

SARF is not specifically a theory about product-related risk so does not make reference to actions like product recall. Modelling SARF in a particular kind of context, like product crises, therefore necessarily requires the addition of elements that represent a recall process. The process of recall is often a key element in responses to product-related crises (Choi and Chung, 2013; Magno, 2012) and in raising public concern (for example, Choi and Lin, 2009b; Desai and Patel, 2014; Feng et al., 2010).

The proposed model takes product recall as an amplification station that influences risk perception in two aspects: the direct effect through product recall information (De Matos and Rossi, 2007; Laufer and Jung, 2010; Umehara and Ohta, 2011) and the indirect effect through recreancy (Bunniran et al., 2009; Souiden and Pons, 2009). Product recall information combines with prior beliefs, social interaction, and direct experience to represent the 'event discovery' component of the model as a whole. The model associates recreancy with both a delay in making a product recall, and in being forced to make an involuntary recall.

Simulation of the partial model shows the expected result: an involuntary recall is more influential in heightening risk perception and in creating amplifying ripples of public concern than a voluntary recall, which indicates that the public is more sensitive to an involuntary recall. This effect seems to be diminished by the mechanism of the model, however. As the media effect is added to the belief updating process, risk amplification during and after the

crisis reduces to a relatively lower level. This is because some weight is assigned to media coverage, which decreases the relative importance of product recall.

Sensitivity analysis has demonstrated that both the degree and the delay of peak risk amplification are sensitive to recall voluntariness and insensitive to recall timing. This leads to the conclusion that the public put a greater emphasis on recall voluntariness than recall timing. It differs from the survey result indicating that respondents weighted recall timing more heavily, with recall timing to voluntariness ratio being 1.3. This distinction lies in the reason that in the model there is quite a short time span between the start of the crisis and the randomised recall, which makes the effect of recall timing on recreancy judgments, and subsequently on risk perception, insignificant. In reality, the recall timing affects the extent to which consumers consider the involved company as acceptably responsible (Magno, 2012; Standop, 2006): the shorter the delay in issuing the recall, the more the perceived social responsibility, and the lower the perceived recreancy. Thus a prompt recall can effectively reduce public perceptions of risk. The result makes it clear that the amplifying effect of recreancy on risk amplification is not correlated with the timing of product recall and pronounced only when a recall is made involuntarily. Decision makers need to be more cautious about social reaction to risk if they recall the defective product reluctantly.

It has to be noted that the recall process takes no account of other recall strategies such as denial and 'super effort' (Souiden and Pons, 2009; Vassilikopoulou et al., 2009b) that are also identified as main types of crisis response. The reason is that the recall model focuses on organizational decision making characterized by an influential, real recall action, while denial means that the company refuses to acknowledge that the product is defective, and a super effort (or an improvement campaign) response seems only to be relevant to the recall of products with minor defects that do not threaten public health and safety (Shrivastava and Siomkos, 1989). Also, the model does not consider the role that a company's reputation (Grunwald and Hempelmann, 2010; Hammond, 2013) or brand equity (Korkofingas and Ang, 2011) plays in determining the impact of product recall on social reaction to the crisis. This needs further investigation.

The interactive influence of recreancy judgments and the media content on risk amplification is an important perspective unexamined in this model. Some studies (Boyd and Jardine, 2011; Yannopoulou et al., 2011) have suggested that media portrayal of risk events can affect the level of social trust in those responsible for managing risk and thereby shapes collective risk response. However, Frewer et al. (2002) demonstrated that trust in regulators was unaffected by media communicated risk of genetically modified foods. Thus the interaction between recreancy and media may vary from case to case, depending on the local and social context of the risk event in question.

## 8.2 Contextual specificity

Calibration of the recall model using empirical data from a public survey about a specific product crisis means that the model is not general: its structure is generic since the model is based on general findings in the literature, but calibrated parameter values are completely specific to the survey context. This section is divided into three subsections, as shown in Figure 8.3. The first subsection examines the generality of the model as a whole and of its three components: event discovery, recreancy, and media. The second subsection deals with survey calibration and what factors related to contextualisation of risk amplification have been overlooked.
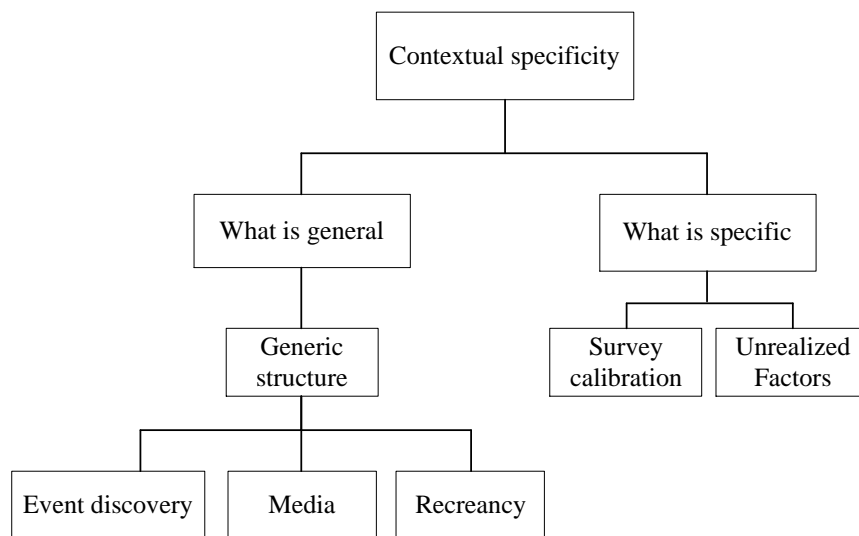


Figure 8.3 Structure of Section 8.2 Contextual specificity

### 8.2.1 What is general in the model

*Generality of the model as a whole*

The model is generic in the sense that its construction is inspired by the general knowledge of social risk amplification and product recall. It synthesizes factors that are identified as significant drivers of risk perception and incorporates interactions between different actors that are seen as influential in past empirical work. From the perspective of the overall structure, the model integrates the components that are primarily necessary for construction of risk perception in a product contamination crisis including an event discovery step, a recreancy assessment step, and media communication. Separating individuals' responses into a risk discovery step and a recreancy judgment step is an important contribution to analysing

social responses to risk, since the literature does not generally distinguish between discovery and judgment of recreancy.

The model structure is highly general in the sense that the mechanisms make no positive assumptions about a context. The decision rules attributed to the agents are not based on expectations about how people and organizations would react differently in different situations, except insofar as different weights might be attached to different elements of the model. Although the model was developed with a Chinese milk products contamination scandal in mind, there was no conscious attempt to capture in the model structure aspects that distinguished this scandal from others.

However, the model is not general at all in the sense that the mechanisms assume a very specific model in which risk perception is a linear additive function of event discovery, recreancy, and media coverage, with arithmetic mean of neighbour beliefs taken as the measure of social interaction. It makes sense to use such simple structures in the absence of knowledge that an alternative would be more appropriate. But if it were known in any particular case that it would be more realistic to use alternatives (for example the updating rules suggested by Busby et al. (2016)), the model becomes inapplicable.

## *Generality of risk discovery*

In the event discovery process, people are exposed to information that makes them aware of the danger and enables them to find out the seriousness of the risk. This is a process of forming estimates of risk through personal discovery, which varies from individual to individual. It is natural to incorporate prior belief, interpersonal communication, and direct experience in this process, as they are common sources from which individuals learn about the risk and vary from individual to individual. The justification for including product recall information is that it provides a signal that a danger concerning the product truly exists or that the risk is more severe than previously believed, although the model assumes that the content of this communication is same to all individuals – the recall message just indicates that there is a product recall. Whereas in actual recall events people interpret and perceive recall messages differently, depending on their perceptions of corporate social responsibility (CSR), the level of blame they attribute to the company, and whether or not they have consumed the product in question (De Matos and Rossi, 2007). Hence in a more realistic model of product recall, recall information would not be a binary variable. Instead, individual's evaluation of recall messages would be affected by various factors, and the risk levels perceived from the messages would be heterogeneous.

## *Generality of media influence*

The communication of product-related crises is critically influenced by media coverage (Yannopoulou et al., 2011). Another source of information is expert risk assessment. However, the public have limited access to technical assessment of risk, leading to the fact that expert assessment of risk is not a normal communication channel in a society.

The model does not distinguish among individual agents in media consumption which in reality will be influenced by demographic characteristics. Instead, all agents receive the same information circulated by the media that eventually goes into the belief updating rule. This assumption is supported by the fact that sometimes different media outlets convey the same message as they tend to repeat each other's reports. Nor does the model deal with the possibility that agents more or less misinterpret media messages. Exploring individual heterogeneity in media consumption and interpretation is an important direction for future work.

Additionally, the consideration of three different roles of media in the model should be applicable to analysis of many risks, as they cover most of the roles that the media can play in risk debates. But it is undeniable that some aspects of the roles are not represented. For example, the media can be a biased observer that disseminates self-serving data (Adams, 1992). In this case, the media follows its own criteria of newsworthiness and routines of news gathering. For simplicity, this can be conceptualised as a situation where the media communicates a risk level that deviates from the objective risk. But it is a challenging task to identify the direction and degree of the deviation, since the character of risk signals is unknown.

The media can also undertake an authority follower role that is accompanied by communicating risk information supporting the particular interests of the authorities. This is similar to the media communication of risk in relation to the Sanlu milk scandal where the media could not report anything negative and had to rigidly adhere to the official word. The literature (Boyd and Jardine, 2011) shows an example of government being an open information source for media reporting on BSE in Canada. The media did not dramatize the risk of BSE but provided accurate descriptions of health and economic consequences facing Canadians. Both cases reflect the significance of media-government engagement in the analysis of risk experience. On the contrary, the media can play its role as a watchdog (Petts et al., 2000) to monitor the conduct of government officials and to guarantee the transparency required for public access to information. The risk information propagating from the media to the public is more objective and communicative. The media uses a neutral tone to report government's action, and modelling this media role will be associated with the introduction of

public perceptions of government incompetence in handling the risk, an important factor affecting public concern for the risk issue.

Another significant role of media concerns the relationship between media and firms: the media can be a partner or an enemy of the involved organization in crisis response. Acting as a partner, the media exchanges information with the organization and becomes part of the response. Roughly, this partnership associates with two possibilities with respect to how the media communicates risk to the public. One is that the media broadcasts accurate, timely information surrounding the story and provides information about what and how people should do to avoid injury and reduce losses. It helps the organization effectively manage the crisis not only by bringing together important information but by preventing message distortion as well. Another possibility is that the coverage needs to be approved by the firm. The media conveys carefully constructed messages only and overlooks facts unfavourable for the firm or information probable to cause huge panic. In this case the media-organization partnership might downplay the risk and / or maintain the credibility of the organization. When the media serves as an enemy of the organization, it reports information incorrectly or deliberately dramatizes the information to attract public attention. For example, it overstates irresponsibility of the company in dealing with product recall such as ambiguous recall announcement and late recall action. Whether the relationship between the company and the media is cooperative or hostile, media communication will affect recreancy judgments of the public. The media influences public risk perception directly through the coverage and indirectly through recreancy.

Figure 8.4 shows the possible media roles discussed above. Future research will benefit from the inclusion of these media representations.
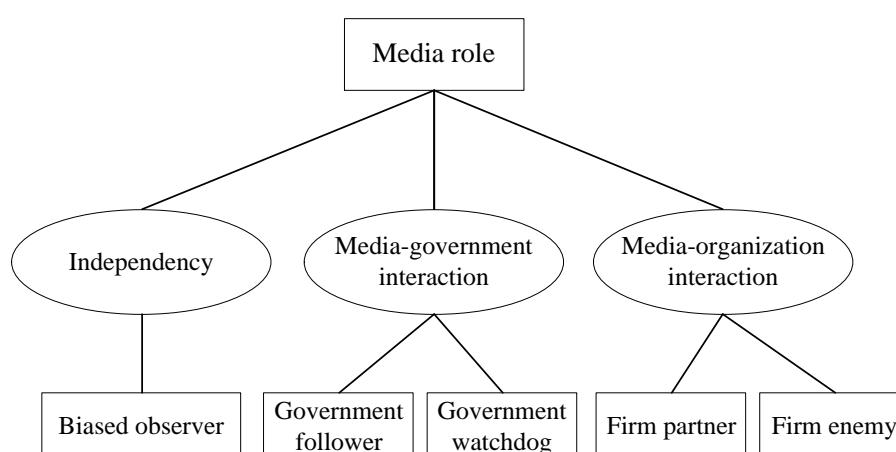


Figure 8.4 Possible media roles for future research

*Generality of recreancy*

Recreancy is a judgment made by a public about an organization's misconduct. Some studies (Burns et al., 1993; Renn et al., 1992) have empirically shown that perceptions of managerial incompetence are predictive of public response to risk events and thereby significant in the amplification process. For the model, the idea of conceptualising recreancy as being a product of timing and voluntariness naturally suits product recall processes. But there are other features of recalls that could influence recreancy judgments, such as apology and factors such as compensation and product replacement offered to consumers (Smith et al., 1996). Examining factors likely to drive recreancy outside of recall timing and voluntariness may be helpful to expand the analysis of potential for recreancy in organizational risk management and requires further attention.

## 8.2.2 What is specific in the model

The calibrated model is highly context specific as the sampling space of the weights in the decision rules is completely dependent on the empirical phenomenon presented in the survey. In this case the survey was conducted specifically in the context of liquid milk contamination. The calibration generated distributions for the weights of multiple information sources that the public consult when forming risk perception, so that each agent follows the same algorithm with a different combination of parameters to modify its risk belief. That is to say, the model is specific to the heterogeneous respondents of the survey about liquid milk contamination. Further empirical work is needed to test whether the decision weights tend to vary from time to time, from issue to issue, from population to population. As Chattoe-Brown (2014) indicates, calibration will leave remaining uncertainty about exact values for average properties in a group, but it will certainly help eliminate extremely unrealistic parameters.

Public risk perception time series from existing empirical studies and other models provide an important demonstration of the influence of social contexts on risk perceptions. The differences in the qualitative patterns of risk perception as well as the magnitude of risk amplification show how context-dependent risk amplification is. For instance, Loewenstein and Mather (1990) have shown that certain cases (i.e. herpes, teenage suicide and illegitimacy, and AIDS) exhibited sudden and substantial surges of concern, while for some cases (i.e. crime, inflation, unemployment, and polio) public risk perception was highly consistent with the objective level of risk. The authors proposed that the major contributor to the distinction was the degree of public familiarity with the problems, a psychological factor that varies with risk issues. Individuals had much less knowledge and direct observation about herpes, teenage suicide and illegitimacy, and AIDS than they had about crime, inflation, unemployment, and

polio, which were closely linked with their lives. Hence, the level of concern for the first four cases could be easily heightened by external influences such as interpersonal communication and media reporting. Burgess (2012) also suggested that unfamiliarity with a hazard was a significant variable stimulating social amplification of risk. Familiarity is a long-term causal factor (Loewenstein and Mather, 1990), so an agent's familiarity level would vary over time and this would add a further element of specificity to a more comprehensive model of risk amplification.

In addition, although all the risk issues analysed by Loewenstein and Mather (1990) showed fluctuations in perceived risks, they took on quite different qualitative features regarding the number and amplitude of peaks and trend of movements. Again, this is probably a product of context. Non-monotonic movements can also be seen from the trajectories of models about multiple societal risks (Busby et al., 2016), zoonotic disease outbreaks (Busby and Onggo, 2013), and BSE in the UK (Bleda and Shackley, 2012). The recall model, in contrast, displays no fluctuations but a rapid growth followed by an immediate decay in risk perception. One of the reasons for this difference is also the context in which the risk issue is situated. In a product recall, the underlying problem is usually a fault with the product, which can be found and then fixed, usually with little doubt that this is the end of the issue. Effectively, this is what the model assumes, because the objective communication level drops immediately. In the case of diseases, it may not be clear when the disease outbreak has definitely finished.

## 8.3 Response to research questions

This section presents a summary of how the model answers the research questions raised in this study, i.e. RQ1: how can we formalise social amplification of risk in the context of a product recall event? RQ2: what can we learn from the formalisation?

### *Response to RQ1: how can we formalise SARF in product recall?*

This study uses an agent-based approach to model and simulate social risk amplification in the way in which SARF cannot be modelled directly. The systematic description of social experience of risk in the original framework is very general. And there are some ambiguities inherent in SARF. For example, Rip (1988) argued that there is not a clear indication of risk experience in the framework, and that SARF centres on the information processing by individuals and evidently neglects the processes of social aggregation. Moreover, the definition of risk amplification is still vague as SARF does not explicitly specify the baseline risk against which amplification can be measured. These issues prevent SARF from being

implemented in a model in any direct way. This study shows how the ambiguities might be resolved, with a more specific model and an agent-based, computational implementation in an organizational context of a product recall event.

RQ1 has been addressed in three main steps. The first step makes a commitment to general mechanisms lying behind social risk amplification: it combines broadcast and narrowcast information channels among a group of actors in a social network and also integrates a risk discovery process and a recreancy judgment process into an individual actor's processing of risk information. This distinction between discovering information about a risk and making a judgment about an organization's conduct seems important. The second step reviews the literature in a more specific domain of organizational activity (in this case, product recall) to develop a set of more specific candidate decision rules behind consumers' responses to organizational crisis of this kind. Rules developed in the above two steps are incorporated in the conceptual model of a social agent developing a risk perception to a product recall. For example, the agents respond to the timing and voluntariness of the recall event. The third step conducts a survey to calibrate the weights within such rules, sampling from the distributions discovered in the survey. This means that the model is then tailored to a particular population responding to a particular risk. Figure 8.5 depicts the general procedure of formalising social risk amplification in the context of a product recall crisis.
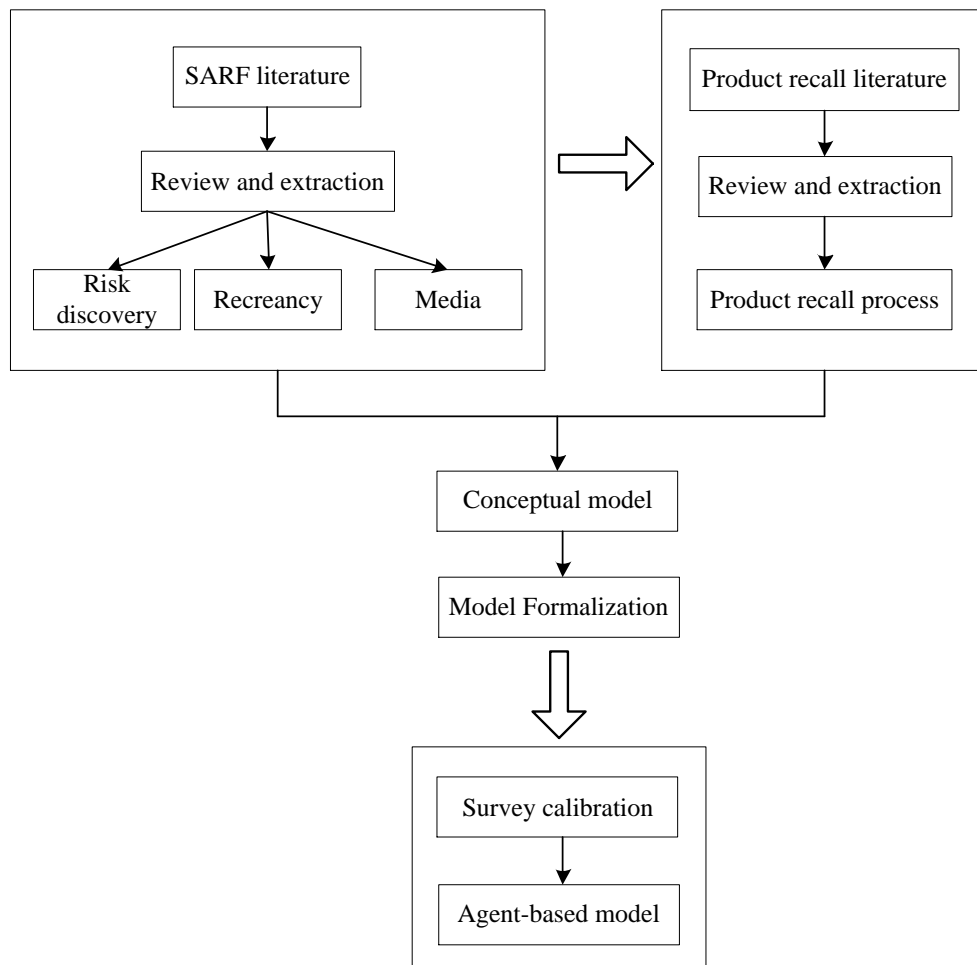
Figure 8.5 Formalisation of social risk amplification in the context of a product recall crisis

In the second step, conceptualisation of product recall is based on selective decision rules extracted from the recall literature, as shown in Figure 8.6.
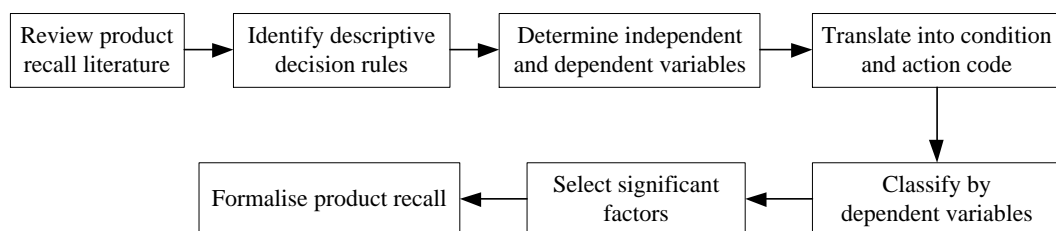


Figure 8.6 Conceptualisation of product recall process

Drawing on significant results of empirical studies, decision rules are based on empirical cause-and-effect relationships. Causes and effects are converted into condition codes and action codes, respectively in the rules. Figure 8.7 displays the mapping between variables and codes. Decision rules are categorized by the condition codes so that appropriate rules can be selected for models of specific contexts in which the particular dependent variables are

relevant. Recall message, recall timing, and recall voluntariness, which are chosen as essential elements of product recall, are incorporated in the two main processes: recall message is integrated into risk discovery, and recall timing and voluntariness are considered as a measure of recreancy. This procedure provides a general approach that is able to transform descriptions of the findings of studies in a particular area of the literature to part of a conceptual model. Other factors (e.g. product involvement, perceived corporate social responsibility, organizational reputation, and so on) have also been proven crucial for individuals' reaction to product recalls but were not incorporated in the model to avoid excessive complexity. They are important candidates for future work in social risk amplification.
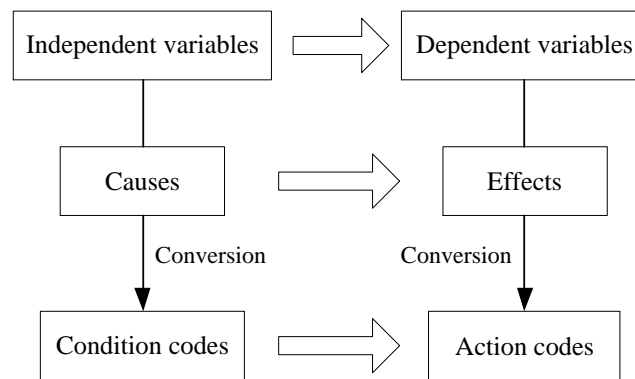


Figure 8.7 Mapping between variables and codes

Figure 8.8 provides a template for model calibration – the third main step. The illustrative case chosen to contextualise the model in this third step had to meet at least the following requirements:

1) it had to be recent so people readily remember,

2) it had to be a case where the involved company took response strategies publicly,

3) it had to be clearly a case in which there was a strong social risk response,

4) it had to be a case where the prime elements (e.g. recreancy) of the model appear to be relevant.
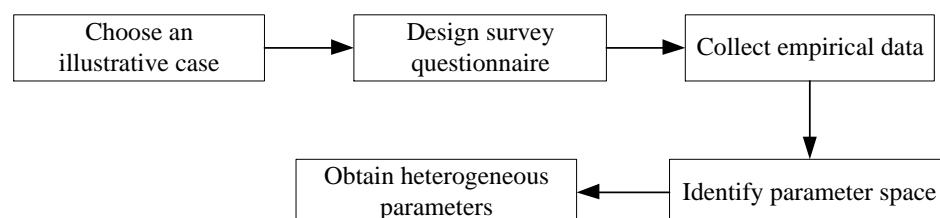


Figure 8.8 Template for model calibration

How to ask questions to help calibrate the weights in decision rules is also an important part of the response to RQ1. As discussed earlier, the design of survey questions asking people to evaluate the relative importance among each pair of information sources has to be based on the premise that there is a uniform way to measure relative importance, for example, using a common scale ranging from 0 to 100%. It represents an attempt to capture an individual's judgment about the significance of risk information in a simple yet effective way, which can then be interpreted in terms of decision weights within the model.

The model uses very simple linear updating rules for agent risk beliefs. This is the most economical approach, given no definite evidence that agents would update their beliefs in a more complex way. Both Axelrod (1997) and Macal and North (2005) have shown that applying simple rules to agent-based models can result in emergent and complex behaviours and reveal important insights on what is being studied. In addition, Axelrod (1997) pointed out that a very simple model does not rule out making potentially interesting extensions to the model subsequently. But there is scope to explore many other processes of interaction between agents and their social neighbours, the broadcast media, and producers dealing with product recalls. This would at least help reveal how sensitive the model would be to assumptions about the interaction process.

## *Response to RQ2: what can we learn from the formalisation?*

The main findings of simulating the model are as follows. *First*, organizational response to a crisis or risk event appears to be a determinant of public perceived risks. Risk amplification occurs, no matter whether the company issues the recall voluntarily or involuntarily, but whether it is voluntary affects the degree of amplification. Thus, managers need to understand concerns that may emerge from organizational activities so that they can devise appropriate response strategies to counter potential negative effects caused by the concerns. But it has to be pointed out that the domination of product recall in the model may lie in the fact that recall information is built into the model as a binary variable (whose value is either 0 or 1). The reality is that the risk people perceive from recall information probably falls on a continuous scale. Organizational communications vary in informant content and information framing in a way that is much more subtle than in the model. As a result, it is difficult to speculate whether this finding is generalizable to other situations where the firms issue a recall but public response to recall is much different from that in the model or where recall processes are more complex than in the model. This needs future work.

*Second*, the evolution of public concern is strongly related to the duration of crisis, given the established assumptions of the model. This underscores the pressure that companies responsible for the crises might face in handling public concern and taking corrective action.

An intensive organizational effort is primarily needed to lessen amplified risk by bringing the crisis to a close quickly. However, the model indicates that amplification peaks at the end of the crisis, and in the real world this is not always the case. For example, Ibuka et al.'s (2010) survey on risk perceptions of 2009 H1N1 influenza in the US showed that perceived probability of H1N1 infection increased over time, while the survey conducted by Lau et al. (2003) on risks of SARS in Hong Kong demonstrated that risk perception peaked around the ceasing of the first phase (when the World Health Organization issued a travel advisory warning for Hong Kong). The model does not take account of such specific influencing events. Early peak of risk perception can also be seen in model outcome by Busby and Onggo (2013).

*Third*, another point regarding the time series of the model is that it appears impossible to completely eliminate the exaggerated perceptions of risk as the residue remains relatively high even after the crisis is resolved. Busby and Onggo's (2013) system dynamics modelling of zoonotic disease outbreaks also produces such a residual effect. In the SARF literature, however, there has been no empirical work on residual concern of the public after the end of a crisis or risk event. It is an issue that is potentially pivotal but has not been investigated in a realistic context. The residue is reflected in the Sanlu case where consumers had extremely weak confidence in Chinese dairy products after the incident (Huang, 2014). In fact, until now Chinese consumers still see foreign baby formula brands as their first choice, and many local brands has suffered sales decline for years (He, 2016).

*Fourth*, the objectivity of media coverage appears to be inversely related to risk amplification. A media that simply follows public opinion is much more influential in heightening risk than an objective one. This echoes the argument that the way the media manipulates coverage primarily affects its ability to generate amplification of risk (Burgess, 2012; Yannopoulou et al., 2011). From this perspective, it is important for companies to realize how information disseminated by the media is framed so as to aid in managing the risk. More quick and effective organizational communication efforts are needed when the media is a strong follower of public opinion.

*Lastly*, sensitivity analysis provides indications on which model parameters have the biggest effects on outcome variables. To be more specific, the initial conditions, contamination level, contamination duration, and recreancy variation (in the case of involuntary recall) are the parameters that risk amplification and delay in peak risk amplification are sensitive to. From an empirical perspective, sensitivity analysis helps prioritize data collection efforts and research needs. The results indicate that validation activities may have to particularly focus on observing the initial state of public perceptions, measuring the objective risk level, and seeking information manifesting public trust in the firm. From a practical perspective, sensitivity analysis helps identify critical control points where managerial actions need to be centred in the course of risk communication. The

sensitivity of risk amplification to recreancy that arises from involuntary, delayed recalls shows that managers need to be especially careful about not recalling products quickly and proactively.

The results of sensitivity analysis represent hypotheses rather than predictions as they are not based on historical data, evidence, or experience. They merely indicate the relationships incorporated in the model. Therefore, a useful programme of future work would be to test these hypotheses empirically. The focus implied by the sensitivity analysis is quite different from the current focus of scholarly empirical research on risk amplification. Little research has dealt with how the initial conditions, objective risk, and trust in the organization contribute to amplified risk during a risk event, with the exception of Freudenburg's (1993; 2003) work on recreancy and Kim et al.'s (2008) work on consumer trust.

# 9 CONCLUSION

This chapter concludes the thesis as a whole. It first identifies contributions that this study has made to research on risk perception and social risk amplification particularly, and then presents key implications derived from the analysis of this study. It ends with a brief summary of the limitations of the work and the associated directions for future research.

## 9.1 Intended contributions

Given the long-standing ambiguities of SARF, for example about what defines an 'amplified' risk response, this study uses an agent-based model to reason about risk amplification from the standpoint of an organization attempting to influence public response. This illustrates issues that have been explored only to a limited extent, such as Freudenburg's (1993) general idea of recreancy, and explores an important context that has received little or no attention as a social risk amplification problem: product risk and recall events. It intends to provide a more precise understanding of social risk amplification and thereby contribute to the broader field of risk perception research. It synthesizes factors obtained from past work on SARF and past product recall studies into a coherent model and explores the implications of simulating this model. The concrete contributions of this thesis are mainly identified in the following two aspects.

First, this thesis provides a pathway to formalising social risk amplification in an organizational context of a recall event. Recall events, although not treated as problems of social risk amplification in the past, are important risk amplification events because the scale of the public response is important to the degree of risk that actually arises. If a public attenuates a product risk it will fail to respond adequately to the recall, and will consequently bear a higher objective risk. Recall events are also inherently interesting as risk amplification issues because there are two, basically opposing effects of the recall. The first is to inform the public of some risk they were probably not aware of before, but the second is to demonstrate to the public that the producer is concerned about the public's welfare and is taking steps to protect it. These steps are likely to be costly to the firm. The aim in formalising our understanding of recall cases is to construct a process in which rules and interactions that determine agents' behaviours are specified. The formalisation developed in this research is achieved by three main steps:

1) developing decision rules behind social risk amplification generally,
2) developing decision rules behind a specific crisis involving product recall,
3) calibrating the weights for the decision rules.

Within these three steps are certain essential aspects:

1) how to operationalize risk perception – an agent's risk belief is shaped by three essential processes: risk discovery, recreancy, and media,

2) how to represent organizational decision making – product recall involves a decision about voluntariness and timing of when to recall a product,

3) how to represent media communication – media potentially plays different roles in shaping risk beliefs,

4) how to perform calibration of certain parameter distributions – by means of a consumer survey asking people to evaluate relative importance of risk information.

Overall, the modelling involves a process of progressively contextualising social risk amplification, integrating qualitative knowledge about decision rules and the connections between the rules of different decision makers with empirical data about the relative importance to decision makers of different information sources. Although the representation of risk decisions and calibration of the model are simple, the model reveals insight into the mechanism of risk amplification (e.g. the model produces a residue of concern after the crisis is terminated) and indicates critical variables (e.g. sensitivity analysis identifies recreancy as an influential factor of risk amplification).

Second, this thesis gives guidance on carrying out research concerning risk amplification: it proposes a method of extracting critical elements from the literature as well as a way of calibrating an agent model using a consumer survey. The procedure of developing decision rules of consumers as they respond to an organizational crisis (see Chapter 5) illustrates how to select factors from statistical findings of studies in a specific domain and to build these factors into an agent-based model. This approach, in principle, applies to situations in which a relatively large number of empirical studies are available in a particular area. It allows researchers to turn from a statistical correlation between two variables to a representation of agents whose decision rules express these relationships. This allows us to go from a model in which relationships are central to a model in which interactions of agents are central. This in turn allows us to model not average effects and average outcomes, but the dynamics of how effects and outcomes evolve over time within a population.

After this formulation of decision rules, the numerical priorities of heterogeneous agents still need to be determined. This comes from a calibration process. The calibration process can serve as a template for building a model of social risk amplification that can be made specific to a particular population and particular product crisis – for example the Chinese population buying infant milk products during a contamination event. A survey was employed as an instrument of calibration for a model of SARF for what is believed to be the first time, and it used a simple and straightforward way of gathering data to design survey questions to assess relative importance of risk information. The disadvantage of utilizing such a survey for

calibration is that it encourages modellers to include only decision rules that are accessible to the decision makers using them, and to leave out those decision rules about which decision makers do not have insight. In other words, the calibration method only examines parameters and relationships that people are able to judge. The recreancy variation (by which recreancy can change when a firm makes a voluntary or an involuntary recall), for example, was not calibrated by the survey, because consumers' recreancy perceptions of a firm represents a psychological state with respect to their belief in misconduct of the firm and it is hard for consumers to quantitatively evaluate the change in such state. Other approaches are needed to identify decision rules when people do not have access to their own rules, involving implied rather than stated priorities. Nonetheless, the calibration presented in this thesis offers a new perspective in micro-validation of SARF models.

## 9.2 Practical implications

The model proposed in this thesis has generated some managerial implications for decision makers responsible for dealing with organizational crises.

First, organizations need to be more serious about the potentially adverse impact engendered by their responses and communications during a recall crisis. The product recall strategy itself can trigger amplification of risk: it clearly indicates that there is some kind of failure, and possibly negligence, in the product, and that there is some level of danger in consuming the product. The risk that people perceive from the recall message influences the formation of their risk beliefs (De Matos and Rossi, 2007; Laufer and Jung, 2010; Umehara and Ohta, 2011). As noted, organizational misconduct not only contributes to exaggerated risk but produces a residue of concern after the crisis is removed. If the organization does not react in a responsible manner (for example, the organization issues a recall involuntarily), it may have far more to lose from product recall than expected – the organization not only loses its consumers' trust and loyalty but suffers from low intentions of the public to purchase its products in the future. Magno (2012) have also suggested that consumers' perceptions of organizational response in a product recall can have a long-lasting impact on their attitude toward the company even after the crisis. While other factors also account for the public's attitude toward risk, by paying more attention to the systemic consequences of its own actions, when responded to by a social network of consumers, the organization can be more proactive in communication with the public.

Second, managerial actions should incorporate examination of the media's role in risk communication. The way in which information disseminated by the media is framed is largely determined by the role that the media is undertaking: media narratives of risk are supported by

self-serving communication (e.g. risk-related stories are based on what the media discovers or the media quotes reporting from other media sources) or result from interactions between the media and other social groups such as government, the public, and the firm. It is not always the case that media coverage elicits significant public concern (for example, Boyd and Jardine, 2011; Chung, 2011; Smith et al., 2013). But knowing the role of media enables the organization to understand to what extent the information that the public receive from the media is accurate and to better estimate the effect of media coverage on public risk perception. In the model, risk amplification was significantly different according to whether the media led public opinion, followed it, or had a mixed strategy. It is important that the organization remains accessible to the media throughout its organizational response in order to deal effectively with public concern aroused by media circulated information, and to help the media lead rather than simply follow public opinion.

## 9.3 Limitations and future work

This study has several limitations that indicate directions for future research. Many of these have been discussed at length in Chapter 8, so the following is a summary of what appear to be the most important of these.

First, the model does not consider the role of government and associated interactions. The most obvious is the interaction between media and government, which is central in risk debates and has received little emphasis so far (Howarth, 2013). Moreover, in the Sanlu milk scandal the central government controlled the flow of information to lead public opinion through imposing censorship on news media (Mooney, 2008). The reason why government is not dealt with as an actor in the proposed model is that there are some uncertainties of modelling media-government interaction. The interaction between media and government can vary depending on risk domain, social context, press freedom, and government policy. And it may also involve some important parameters such as public perceptions of government incompetence in the handling of risk and shift of media roles during the course of a risk event. Therefore, sufficient theoretical and empirical evidence is necessary to investigate the characteristic and inherent complexity of the relationship between media and government before representing their interaction using a model.

Second, some social processes and related decision rules have been simplified in the model. In particular:

1) Recall information is simply conceptualised as a binary variable indicating whether there is a recall or not. This may have magnified the contribution of product recall to risk amplification in the model (for example, according to simulation experiments in Chapter 5,

product recall information appears to dominate the exogenous peak of risk perception). In reality a product recall message is more complex than in the model: it presents the defect and declares a recall, and risk perceived from the message probably falls on a continuous scale which is heterogeneous across the population.

2) Measured by recall timing and voluntariness, recreancy does not take into account other factors that also reflect managerial incompetence, such as compensation and product replacement (Smith et al., 1996). This is because the model primarily focuses on organizational response to a crisis (i.e. the recall itself) and ignores resolution of a crisis (i.e. follow-up actions). But recreancy belief is a complex construct with broad drivers (Freudenburg, 1993) and not stable in nature, so the lack of analysis of the effect of follow-up actions is a simplification.

3) Beyond recall information and recreancy, other factors have been overlooked to explore the effect of product recall on public perceptions of risk, for example, an organization's reputation (Hammond, 2013; Grunwald and Hempelmann, 2010) and brand equity (Korkofingas and Ang, 2011), and individuals' product involvement (Choi and Chung, 2013; Choi and Lin, 2009a) and blame attribution (Bunniran et al., 2009; Magno, 2012). These factors capture individuals' impression of the organization and their connections with the product rather than the organization's response. In other words, the risk that individuals perceive in a recall process is influenced not only by managerial actions but by their own more general judgment about the organization and involvement with its products.

Another social process that has been simplified in the model is media communication. The simplification is embodied in two aspects. One simplification is the social processing of media coverage. The model assumes that media consumption is homogeneous across individual agents. People generally expose themselves to news information that they trust (Tsfati and Cappella, 2003) or consume information that is readily accessible to them, and individual demographics including age, education, and income level also influence media consumption (Taneja et al., 2012). In a heterogeneous population of public agents, it may be less realistic to presume a uniform consumption of news coverage. Besides, a wide range of studies (for example, Bachmann et al., 2010; Harrison and Cantor, 1997; McCool et al., 2005) have shown that there is a link between exposure to media and the behavioural response of individuals. Thus the model is likely to have under-stated the variance of collective risk responses. Another assumption concerning media communication is that individual agents do not misinterpret the information transmitted by media. When it comes to perception of media messages, however, reception does not necessarily produce correct understanding, especially if the content is complex or technical as is often the case with food contamination. A future step needs to develop decision rules on media consumption and interpretation through

surveying literature in the field of media studies. This will contribute to the SARF literature in that little research has been undertaken to integrate such rules with SARF.

The other simplification in relation to the media is that the model does not deal with time delay that may exist in the feedback between the public and the media. Burns and Slovic's (2007) model has shown that information delay is one of the important contributors to social risk amplification. It is unclear how delay relates to the amplification process in the model presented in this thesis, but it deserves an attempt to explore the effect of delay in future work.

Finally, there are limitations in macro-validation. The difficulty of empirically validating the agent-based model at the macro-level mostly lies in the problem of observing a time series showing public risk perception and expert or objective risk assessments over the course of a crisis. Also, the model is characterized by several parameters, and any empirical dataset has to be matched on each parameter in order to ensure that it is the appropriate model generating the output that the dataset is compared with. What is more, since the model output is trace of risk perception before and during and after a recall crisis, empirical evidence should also across these periods. Accordingly, data collection activities need to be implemented beyond the life cycle of the crisis. This is a significant challenge, requesting a high cost of time and effort and raising some fundamental methodological problems:

1) One approach to collecting time series data about a crisis is to wait for a crisis and then start data collection. However, it is very hard to anticipate the occurrence of a risk event or have resources in place ready for this. Moreover, time series before the crisis starts will be missed due to the unpredictability of the crisis.

2) Another approach is to acquire data from a source that collects this kind of time series continually, during times of crisis and non-crisis. But it is very hard to find any context in which such data is available.

The absence of macro-validation in this study limits the grounds on which to place confidence in the outcomes of the recall model. Despite these limitations, modelling of this kind helps clarify our understanding of an important problem. And, in fact, the difficulty of obtaining data means that modelling may be the only realistic option we have at this stage.

In summary, the limitations of this study suggest future investigation in several directions. First, it would be beneficial to incorporate the interaction between media and government into the model. This would involve dealing with the nature of the media-government relationship that essentially determines the role of media and public perceptions of government competence in risk communication. For example, a model of a case in China would involve some restriction on risk levels that the media could broadcast as well as censorship of specific content (for example news of contamination, or source of contamination). It might also involve a government actor playing a role in the recall announcement – perhaps delaying it if the contamination is at such a high level that there could be significant social unrest. Second,

a future step is needed to add complexity to some social processes in the model including product recall and media communication. For example, heterogeneity could be added to media consumption and interpretation, with different individuals receiving different amounts of risk information communicated by the media and misinterpreting media coverage to different degrees. And the recall decision by the producer could become a function of the change in consumption levels of its product. Third, validating the model at the macro-level is an important direction of further investigation. Since it is very hard to obtain time series data on risk perception, the next step may be to work out how to analyse social media content to validate a model like this. An example of prior work of this kind is Klimek et al.'s (2011) analysis of Twitter time series, which could be adapted to be used in a SARF study.

# TABLE OF SYMBOLS

| Symbol | Name | Explanation | Where it is introduced |
|--------|------|-------------|------------------------|
| $N$ | Number of agents | Number of public agents | Section 5.2.1.1 |
| $i$ | Agent | An individual public agent | Section 5.2.1.1 |
| $t$ | Time | Model simulation time | Section 5.2.1.1 |
| $b_i(t)$ | Risk belief | Agent $i$'s belief of probability that it will experience product contamination | Section 5.2.1.1 |
| $I$ | Maximum initial condition | Defines initial risk and recreancy belief | Section 5.2.1.1 |
| $K$ | Number of neighbours | Number of neighbours in a perfectly mixed population and in initial lattice | Section 5.2.1.1 |
| $j$ | Numerical order | Numerical order of neighbours | Section 5.2.1.1 |
| $b_{nj}(t)$ | Neighbour risk belief | Neighbour $j$'s belief of probability of experiencing product contamination | Section 5.2.1.1 |
| $C(t)$ | Contamination level | Objective probability of an agent experiencing product contamination | Section 5.2.1.2 |
| $C_{low}(t)$ | Low contamination level | Level before and after crisis | Section 5.2.1.2 |
| $C_{high}(t)$ | High contamination level | Level during the crisis | Section 5.2.1.2 |
| $T_{start}$ | Contamination start period | Time when the crisis starts | Section 5.2.1.2 |
| $T_{end}$ | Contamination end period | Time when the crisis ends | Section 5.2.1.2 |
| $e_i(t)$ | Direct experience | Whether agent $i$ has direct experience with product contamination or not | Section 5.2.1.2 |
| $m_i(t)$ | Random number | Randomises agent $i$'s experience with product contamination | Section 5.2.1.2 |
| $R_H$ | Perceived risk threshold | Defines when perceived risk changes consumer responses | Section 5.2.1.3 |
| $I_H$ | Involvement threshold | Defines when involvement with product changes consumer attitudes | Section 5.2.1.3 |

| | | | |
|---|---|---|---|
| $S_H$ | Sincerity threshold | Defines when sincerity of apology changes consumer attitudes | Section 5.2.1.3 |
| $c$ | Constant | Represents the effects of involvement and sincerity on consumer attitudes | Section 5.2.1.3 |
| $a(t)$ | Recall announcement | Whether a recall announcement is made or not | Section 5.2.1.3 |
| $r(t)$ | Product recall | Whether a recall is in force or not | Section 5.2.1.3 |
| $R_i(t)$ | Recreancy belief | Agent $i$'s belief that the producer has betrayed the public trust and fails to fulfil its obligations | Section 5.2.1.4 |
| $D$ | Recreancy increment | Amount by which a recall increases recreancy | Section 5.2.1.4 |
| $B$ | Risk perception threshold | Defines when a recall increases recreancy | Section 5.2.1.4 |
| $T_{a(t)=1}$ | Recall timing | Time when a recall announcement is made | Section 5.2.1.4 |
| $h_i(t)$ | Hearing recall | whether agent $i$ has already heard the recall or not | Section 5.2.1.4 |
| $v(t)$ | Recall voluntariness | Whether recall is voluntary or involuntary | Section 5.2.1.4 |
| $E$ | Recreancy variation | Amount by which recall voluntariness changes recreancy | Section 5.2.1.4 |
| $\lambda$ | Weight of 'event discovery' | Weight given to 'event discovery' in the partial model with recreancy | Section 5.2.1.4 |
| $\delta$ | Weight of 'recreancy' | Weight given to 'recreancy' in the partial model with recreancy | Section 5.2.1.4 |
| $M(t)$ | Media communicated risk | Risk disseminated by the media | Section 5.2.1.5 |
| $\alpha$ | Weight of 'event discovery' | Weight given to 'event discovery' in the full model | Section 5.2.1.5 |
| $\beta$ | Weight of 'recreancy' | Weight given to 'recreancy' in the full model | Section 5.2.1.5 |
| $\gamma$ | Weight of media communication | Weight given to perception expressed in the 'media' in the full model | Section 5.2.1.5 |

| | | | |
|---|---|---|---|
| $df$ | Degrees of freedom | Number of values in the final calculation of a $t$-test statistic | Section 5.2.2 |
| $p$ | $p$-value | Probability of finding the observed results or results of greater magnitude when the null hypothesis is true | Section 5.2.2 |
| $P$ | Rewiring probability | Probability of reconnecting a lattice edge | Section 5.3 |
| $Q_7$ | Questionnaire item $Q_7$ | Comparison between own perception and other people's perceptions | Section 6.2.2 |
| $Q_8$ | Questionnaire item $Q_8$ | Comparison between noticing contamination and other people's perceptions | Section 6.2.2 |
| $Q_9$ | Questionnaire item $Q_9$ | Comparison between recall notice and other people's perceptions | Section 6.2.2 |
| $Q_{10}$ | Questionnaire item $Q_{10}$ | Comparison between recall timing and voluntariness | Section 6.2.2 |
| $Q_{11}$ | Questionnaire item $Q_{11}$ | Comparison between trust in the producer and other people's perceptions | Section 6.2.2 |
| $Q_{12}$ | Questionnaire item $Q_{12}$ | Comparison between media communicated risk and other people's perceptions | Section 6.2.2 |
| $w_1$ | Weight of 'event discovery' | Weight given to 'event discovery' | Section 6.7 |
| $w_2$ | Weight of prior belief | Weight given to prior belief | Section 6.7 |
| $w_3$ | Weight of social interaction | Weight given to social interaction | Section 6.7 |
| $w_4$ | Weight of direct experience | Weight given to direct experience | Section 6.7 |
| $w_5$ | Weight of product recall information | Weight given to product recall information | Section 6.7 |
| $w_6$ | Weight of 'recreancy' | Weight given to 'recreancy' | Section 6.7 |
| $w_7$ | Weight of communication from 'media' | Weight given to communication from 'media' | Section 6.7 |
| $W$ | Weight array | Array of weights of an information source | Section 6.7 |
| $SP1$ | Shape parameter | One shape parameter of beta distribution of an information source | Section 6.7 |

| | | | |
|---|---|---|---|
| $SP2$ | Shape parameter | The other shape parameter of beta distribution of an information source | Section 6.7 |
| $k$ | Kolmogorov-Smirnov test statistic | Measures the distance between the empirical distribution function of weight of an information source and the cumulative distribution function of beta distribution | Section 6.7 |
| $X$ | Original ratio | Original ratio of recall timing to voluntariness | Section 6.7 |
| $Y$ | Normalized ratio | Normalized ratio of recall timing to voluntariness | Section 6.7 |
| $a$ | Lower bound | Lower bound of original ratios | Section 6.7 |
| $b$ | Upper bound | Upper bound of original ratios | Section 6.7 |
| $D_i$ | Recreancy increment | Amount by which a recall increases agent $i$'s recreancy belief | Section 6.7 |
| $E_i$ | Recreancy variation | Amount by which recall voluntariness changes agent $i$'s recreancy belief | Section 6.7 |
| $H$ | Maximum recreancy variation | Maximum by which recreancy can change | Section 6.7 |
| $B_i$ | Risk perception threshold | Defines when a recall increases agent $i$'s recreancy belief | Section 6.8 |
| $S$ | Maximum perception threshold | Defines when a recall increases recreancy | Section 6.8 |
| $\mu_m$ | Mean risk amplification over crisis | Mean ratio of public risk perception to the objective risk during the crisis | Section 7.1.1 |
| $\mu_p$ | Peak risk amplification | Ratio of peak risk perception to the objective risk | Section 7.1.1 |
| $\varphi_c$ | Peak delay from crisis start | Time delay between peak risk amplification and crisis start | Section 7.1.1 |
| $\varphi_r$ | Peak delay from recall start | Time delay between peak risk amplification and recall start | Section 7.1.1 |

| | | | |
|---|---|---|---|
| $Z$ | Number of runs | Number of times the model is replicated | Section 7.1.1 |
| $T_{peak}$ | Timing of peak risk perception | Time when peak risk perception in a single run arises | Section 7.1.1 |
| $\mu_s$ | Peak risk perception | Peak risk perception in a single run | Section 7.1.1 |
| $F$ | Welch ANOVA statistic | Determines whether there are any statistically significant differences among the mean weights of different information sources | Section 8.1.1 |
| $L(P)$ | Characteristic path length | Number of edges in the shortest path between two nodes, averaged over all pairs of nodes | Section 8.1.1 |

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# APPENDIX

## A Extraction of decision rules

The table below demonstrates the decision rules of different agents (e.g. consumers, organizations, and media) extracted from empirical studies on product recall crises. It consists of overall seven columns: reference, context, agent, condition, action, condition code, and action code. Agent is the one that makes decisions. Conditions and actions are descriptions of the causes (independent variables) and effects (dependent variables) of agent behaviour, which are converted into condition codes and action codes, respectively. On the whole, the decision rules work in such a way that in <context>, for <agent>, if <condition code>, then <action code>.

| Reference | Context | Agent | Condition | Action | Condition Code | Action Code |
|---|---|---|---|---|---|---|
| Choi, J., & Chung, W. (2013). Analysis of the interactive relationship between apology and product involvement in crisis communication: An experimental study on the Toyota recall crisis. *Journal of Business and Technical Communication*, 27(1), 3-31. | Toyota recall crisis | Consumers | Consumers are highly involved with the organization or its products and perceive the CEO's apology speech as truly sincere. | Consumers' attitude toward the organization's reputation is the same as it was before the crisis. | Involvement > $I_H$ Sincerity (Apology) > $S_H$ | Reputation$_t$ = Reputation$_{t-1}$ |
| Choi, Y., & Lin, Y. H. (2009a). Consumer response to crisis: Exploring the concept of involvement in Mattel product recalls. *Public Relations Review*, 35(1), 18-22. | 2007 Mattel toy recalls | Consumers | Consumers are highly involved with the recalls. | Consumers perceive increasingly high reputation in China over time. | Involvement > $I_H$ | (Perceived Reputation)$_t$ = (Perceived Reputation)$_{t-1}$ + $c$ × Involvement |

| | | | | | | |
|---|---|---|---|---|---|---|
| Choi, Y., & Lin, Y. H. (2009b). Consumer responses to Mattel product recalls posted on online bulletin boards: Exploring two types of emotion. *Journal of Public Relations Research*, 21(2), 198-207. | 2007 Mattel toy recalls | Consumers | The more consumers are alerted to a crisis | The more negative attitude they have toward organizational reputation. | Alert $> A_H$ | $\text{Reputation}_t = \text{Reputation}_{t-1} + c \times \text{Alert}$ |
| Souiden, N., & Pons, F. (2009). Product recall crisis management: the impact on manufacturer's image, consumer loyalty and purchase intention. *Journal of Product & Brand Management*, 18(2), 106-114. | Automobile recalls | Consumers | The organization adopts voluntary recall and improvement campaigns. | Consumers have a positive image of the manufacturer. | Voluntary Recall = True Improvement Campaigns = True | $\text{Image}_t = \text{Image}_{t-2} + c \times \text{Voluntary Recall} \times \text{Improvement Campaigns}$ |
| | | Consumers | The organization refuses to acknowledge the defect presented in the product. | Consumers have a significantly negative image of the manufacturer. | Denial = True | $\text{Image}_t = \text{Image}_{t-1} + + c \times \text{Denial}$ |
| Standop, D. (2006). *Product recall versus business as usual: a preliminary analysis of decision-making in potential product-related crises*. 99th EAAE Seminar on 'Trust and Risk in Business Networks'. February 8-10, 2006. Bonn, Germany. | Bicycle recall in the Western parts of Germany | Consumers | Consumers believe that there is a deferral of the recall. | Consumers perceive a bad image of the organization. | Time (Taken to Issue Recall) $> T_H$ | $\text{Image}_t = \text{Image}_{t-1} + c \times \text{Time (Taken to Issue Recall)}$ |
| Copeland, T., Jackson, G., & Morgan, F. (2004). An update on product recalls. *Journal of Marketing Channels*, 11(2-3), 103-121. | Product recall | Consumers | Consumers believe recalls to be less serious or the true nature of danger is not manifest. | Consumers tend to ignore recalls. | Severity (Recall) $< S_H$ | $(\text{Behavioural Intention})_t = (\text{Behavioural Intention})_{t-1}$ |
| De Matos, C. A., & Rossi, C. A. V. (2007). Consumer reaction to product recalls: factors influencing product judgement and behavioural intentions. *International Journal of Consumer* | Automobile recall in Brazil | Consumers | Consumers perceive lower (higher) danger in the defective product. | Consumers show more favourable (unfavourable) behavioural intentions toward the brand recalled. | Perceived Risk $< R_H$ | $(\text{Behavioural Intention})_t = (\text{Behavioural Intention})_{t-1} + c \times \text{Perceived Risk} \times \text{Perceived Importance (Recall Message)} \times$ |
| | | | Consumers attach greater (smaller) importance to | | Perceived Importance (Recall Message) $> I_H$ | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Studies*, 31(1), 109-116. | | | the recall message. | | | Product Judgement × Ownership |
| | | | Consumers have a positive (negative) product judgement. | | Product Judgement > $J_H$ | |
| | | | Consumers (do not) have a car made by the brand recalled. | | Ownership = True | |
| Hammond, R. G. (2013). Sudden Unintended Used-Price Deceleration? The 2009-2010 Toyota Recalls. *Journal of Economics & Management Strategy*, 22(1), 78-100. | 2009-2010 Toyota recalls and 1980s Audi recalls | Consumers | The organization launches product recalls. | Consumers' responses to negative product-quality information depend on company reputation rather than product quality. | Recall = True | (Behavioural Intention) $_t$ = (Behavioural Intention) $_{t-1}$ + $c$ × Organizational Reputation |
| Aouba, A., Harroche, A., Frenzel, L., Torchet, M. F., Rothschild, C., Francois, I., & Mamzer-Bruneel, M. F. (2015). Batch recall of French plasma-derived products due to variant Creutzfeldt-Jakob disease risk: the psychological impact on haemophilic patients, changes in their therapeutic demands and behaviour and ethical considerations. *Haemophilia*, 21, 27-33. | Batch recall of plasma-derived products (PdP) | Consumers | Consumers are accustomed to using PdP. | Consumers express lower depression and anxiety on PdP and fear an increased risk of inhibitor with recombinant products (RP), thus they will continue to use PdP. | Preference (Product) = PdP | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ |
| | | Mothers | Mothers exhibit a high level of parental guilt. | Mothers suffer from high psychological impact and ask for a switch from PdP to recombinant products (RP). | Parental Guilt > $G_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Parental Guilt |
| Choi, J., & Chung, W. (2013). Analysis of the interactive relationship between apology and product involvement in crisis communication: An experimental study on the Toyota recall crisis. *Journal of Business and Technical* | Toyota recall crisis | Consumers | Consumers are highly involved with the organization or its products and perceive the CEO's apology speech as truly sincere. | Consumers are not more likely to purchase a Toyota vehicle in the future. | Involvement > $I_H$ Sincerity (Apology) > $S_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Communication*, 27(1), 3-31. | | Consumers | The organization's reputation is restored. | Consumers do not tend to purchase its products in the future. | Reputation $_t$ = Reputation $_{t-1}$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ |
| | | Consumers | Consumers perceive the CEO's apology as less sincere. | Consumers are more likely to be hesitant to purchase its products. | Sincerity (Apology) < $S_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Sincerity (Apology) |
| Choi, Y., & Lin, Y. H. (2009b). Consumer responses to Mattel product recalls posted on online bulletin boards: Exploring two types of emotion. *Journal of Public Relations Research*, 21(2), 198-207. | 2007 Mattel toy recalls | Consumers | Consumers feel fear and worry in the recalls. | Consumers do not boycott Mattel's products. | Fear > $F_H$<br>Worry > $W_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ |
| Freedman, S., Kearney, M., & Lederman, M. (2012). Product recalls, imperfect information, and spillover effects: Lessons from the consumer response to the 2007 toy recalls. *Review of Economics and Statistics*, 94(2), 499-516. | 2004-2007 U.S. toy recalls | Consumers | The manufacturers launch product recalls. | Consumers continue to purchase other types of toys produced by manufacturers involved in the recalls. | Recall = True | Purchase Intention (Other Types) $_t$ = Purchase Intention (Other Types) $_{t-1}$ |
| Jung, H. K. (2009). *Product recalls: Consumer reaction and blame attributions*. Ph.D. The University of Wisconsin. | Automobile recall | Consumers | Consumers perceive corporate social responsibility as high. | Consumers are more likely to purchase the product in the future. | Perceived Corporate Social Responsibility > $CSR_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Perceived Corporate Social Responsibility × Perceived Corporate Expertise Difference × Perceived Brand Value |
| | | | Consumers perceive corporate expertise difference as high. | | Perceived Corporate Expertise Difference > $D_H$ | |
| | | | Consumers perceive brand value as high. | | Perceived Brand Value > $V_H$ | |
| | Laptop computer recall | Consumers | Consumers perceive a high (low) level of risk for the recalled product. | Consumers' willingness to buy the recalled product is influenced. | Perceived Risk > $R_H$ | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Perceived Risk |

| | | | | | | |
|---|---|---|---|---|---|---|
| Marsh, T. L., Schroeder, T. C., & Mintert, J. (2004). Impacts of meat product recalls on consumer demand in the USA. *Applied Economics*, 36(9), 897-909. | U.S. meat product recalls | Consumers | Consumers have access to current and lagged meat recall information. | Consumers reduce their demand for beef and pork due to decreased quality. | Availability (Recall Information) = True | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Perceived Quality |
| | | Consumers | The organization launches current period poultry recalls. | Consumers perceive a decrease in product quality and reduce poultry consumption significantly. | Current Period Recall (Poultry) = True | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Perceived Quality |
| | | Consumers | Consumers receive media information covering meat recall events. | Consumer demand does not change. | Recall Portrayal (Consumers) = Recall Portrayal (Media) | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ |
| Souiden, N., & Pons, F. (2009). Product recall crisis management: the impact on manufacturer's image, consumer loyalty and purchase intention. *Journal of Product & Brand Management*, 18(2), 106-114. | Automobile recalls | Consumers | The organization refuses to acknowledge the defect presented in the product. | Consumers are not likely to purchase the product. | Denial = True | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-1}$ + $c$ × Denial |
| | | Consumers | The organization adopts voluntary recall and improvement campaigns. | Consumers respond more actively to improvement campaigns than voluntary recall in terms of purchase intention. | Voluntary Recall = True Improvement Campaigns = True | (Purchase Intention) $_t$ = (Purchase Intention) $_{t-2}$ + $c$ × Voluntary Recall × Improvement Campaigns |
| Choi, J., & Chung, W. (2013). Analysis of the interactive relationship between apology and product involvement in crisis communication: An experimental study on the Toyota recall crisis. *Journal of Business and Technical Communication*, 27(1), 3-31. | Toyota recall crisis | Consumers | Consumers are highly involved with the organization or its products and perceive the CEO's apology speech as truly sincere. | The apology has more positive effects on consumers' attitude toward the organization. | Involvement > $I_H$ Sincerity (Apology) > $S_H$ | Attitude $_t$ = Attitude $_{t-1}$ + $c$ × Involvement × Sincerity (Apology) |
| | | Consumers | Consumers perceive the CEO's apology as less sincere. | Consumers are more likely to retain a negative attitude toward the organization. | Sincerity (Apology) < $S_H$ | Attitude $_t$ = Attitude $_{t-1}$ + $c$ × Sincerity (Apology) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Germann, F., Grewal, R., Ross, Jr. W. T., & Srivastava, R. J. (2014). Product recalls and the moderating role of brand commitment. *Marketing Letters*, 25(2), 179-191. | Automobile recalls | Consumers | Consumers are highly committed to the product involved in low (high) severity recalls. | Consumers express less (more) attitude change and less (more) negative responses than those less committed. | Commitment > $C_H$ <br><br> Severity (Recall) < $S_H$ | Attitude $_t$ = Attitude $_{t-1}$ + $c$ × Commitment × Severity (Recall) |
| Venugopal, P., Soni, A., Tiwari, R., & Gupta, S. (2012). Product recall: Effect on brand perception. *International Journals of Marketing and Technology*, 2(12), 199-208. | Dell laptop battery recall and Toyota car recall | Consumers | Consumers perceive that the company acts in a socially responsible manner. | Consumers hold more favourable feelings for the company. | Perceived Corporate Social Responsibility > $CSR_H$ | Attitude $_t$ = Attitude $_{t-1}$ + $c$ × Perceived Corporate Social Responsibility |
| Magno, F. (2012). Managing product recalls: The effects of time, responsible vs. opportunistic recall management and blame on consumers' attitudes. *Procedia-Social and Behavioral Sciences*, 58, 1309-1315. | Laptop recall | Consumers | The company is not active and does not start the recall immediately after the first signals of potential injuries. | Consumers exhibit a negative brand attitude toward the company. | Time (Taken to Issue Recall) > $T_H$ | (Brand Attitude) $_t$ = (Brand Attitude) $_{t-1}$ + $c$ × Time (Taken to Issue Recall) |
| | | Consumers | Consumers perceive that the company has managed the product recall in an opportunistic (a socially responsible) way. | Consumers have a negative (positive) post-recall brand attitude. | Perceived Corporate Social Responsibility < $CSR_H$ | Brand Attitude (Post-recall) $_t$ = Brand Attitude (Pre-recall) $_{t-2}$ + $c$ × Perceived Corporate Social Responsibility × Blame Attribution |
| | | | Consumers (do not) blame the company for the product crisis. | | Blame Attribution = True | |
| Korkofingas, C., & Ang, L. (2011). Product recall, brand equity, and future choice. *Journal of Marketing Management*, 27(9-10), 959-975. | Mp3 player recall | Consumers | The organization has a strong brand. | Consumers downgrade their evaluations of brand equity. | Brand > $B_H$ | (Brand Equity) $_t$ = (Brand Equity) $_{t-1}$ + $c$ × Brand × Perceived Severity × Perceived Speed (Response) |
| | | | Consumers regard the severity of the problem as high. | | Perceived Severity > $S_H$ | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Consumers perceive a slow response of the company in handling the product recall crisis. | | Perceived Speed (Response) < $S_H$ | |
| Aouba, A., Harroche, A., Frenzel, L., Torchet, M. F., Rothschild, C., Francois, I., & Mamzer-Bruneel, M. F. (2015). Batch recall of French plasma-derived products due to variant Creutzfeldt-Jakob disease risk: the psychological impact on haemophilic patients, changes in their therapeutic demands and behaviour and ethical considerations. *Haemophilia*, 21, 27-33. | Batch recall of plasma-derived products (PdP) | Consumers | Consumers are informed of the batch recall of plasma-derived products (PdP). | A large proportion of consumers exhibit normal depression but higher anxiety about the risk of variant Creutzfeldt-Jakob disease (vCJD) infection and switch from PdP to recombinant products (RP). | Recall (PdP) = True | (Number of Consumers) $_t$ = (Number of Consumers) $_{t-1}$ + $c$ × Depression Level × Anxiety Level |
| De Matos, C. A., & Rossi, C. A. V. (2007). Consumer reaction to product recalls: factors influencing product judgement and behavioural intentions. *International Journal of Consumer Studies*, 31(1), 109-116. | Automobile recall in Brazil | Consumers | Consumers perceive the company as high (low) in social responsibility. | Consumers give positive (negative) evaluations for the product. | Perceived Corporate Social Responsibility > $CSR_H$ | (Product Judgement) $_t$ = (Product Judgement) $_{t-1}$ + $c$ × Perceived Corporate Social Responsibility × Blame × Ownership |
| | | | Consumers attribute smaller (higher) blame to the company for the defect presented in the recall message. | | Blame < $B_H$ | |
| | | | Consumers (do not) have a car made by the brand recalled. | | Ownership = True | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bunniran, S., McCaffrey, D. J., Bentley, J. P., & Bouldin, A. S. (2009). Pharmaceutical product withdrawal: Attributions of blame and its impact on trust. *Research in Social and Administrative Pharmacy*, 5(3), 262-273. | Hypothetical pharmaceutical product market withdrawal | Consumers | The organization launches a pharmaceutical product withdrawal. | Blaming appears to be no different between consumers on a withdrawn product and those on a product in the same therapeutic class. | Recall = True | Blame Attribution (Consumers Consuming a Withdrawn Product) = Blame Attribution (Consumers Consuming a Substitute Product) |
| Choi, Y., & Lin, Y. H. (2009a). Consumer response to crisis: Exploring the concept of involvement in Mattel product recalls. *Public Relations Review*, 35(1), 18-22. | 2007 Mattel toy recalls | Media | Mattel issues toy recalls. | Chinese manufacturers are portrayed by the media as a main culprit of the crisis more than twice as often as Mattel. | Recall = True | Probability (Main Culprit = Chinese Manufacturers) > 2 × Probability (Main Culprit = Mattel) |
| | | Consumers | Consumers are highly involved with the recalls. | Consumers blame Mattel most frequently, followed by China. | Involvement > $I_H$ | Probability (Blame Attribution = Mattel) > Probability (Blame Attribution = Chinese Manufacturers) |
| | | Consumers | Mattel issues toy recalls. | Highly involved consumers blame Mattel most frequently, while the media attribute blame to Chinese manufacturers. | Recall = True | Blame Attribution (Highly Involved Consumers) = Mattel Blame Attribution (Media) = Chinese Manufacturers |
| Grunwald, G., & Hempelmann, B. (2010). Impacts of reputation for quality on perceptions of company responsibility and product-related dangers in times of product-recall and public complaints crises: Results from an empirical investigation. *Corporate Reputation Review*, 13(4), 264-283. | Fictitious bicycle recall in Germany | Consumers | Consumers consider the organization as highly reputable before the crisis. | Consumers are more likely to perceive the organization as responsible in managing the recall. | Perceived Pre-crisis Reputation > $R_H$ | (Perceived Responsibility) $_t$ = (Perceived Responsibility) $_{t-1}$ + $c$ × Perceived Pre-crisis Reputation |
| Choi, Y., & Lin, Y. H. (2009a). Consumer response to crisis: Exploring | 2007 Mattel toy recalls | Consumers | Mattel issues toy recalls. | The frequency of anger toward Mattel among | Recall = True | Probability (Anger) $_t$ = Probability (Anger) $_{t-1}$ + $c$ × Involvement |

| | | | | | | |
|---|---|---|---|---|---|---|
| the concept of involvement in Mattel product recalls. *Public Relations Review*, 35(1), 18-22. | | | | highly involved consumers increase over time. | | |
| Choi, Y., & Lin, Y. H. (2009b). Consumer responses to Mattel product recalls posted on online bulletin boards: Exploring two types of emotion. *Journal of Public Relations Research*, 21(2), 198-207. | 2007 Mattel toy recalls | Consumers | Mattel announces the first toy recall. | Consumers express alert most frequently. | Recall (the First) = True | Probability (Alert) > Probability (Other Emotions) |
| | | Consumers | Mattel announces the second, the third, and the fourth toy recalls. | Consumers express anger most frequently. | Recall (the Second, the Third, and the Fourth) = True | Probability (Anger) > Probability (Other Emotions) |
| Grunwald, G., & Hempelmann, B. (2010). Impacts of reputation for quality on perceptions of company responsibility and product-related dangers in times of product-recall and public complaints crises: Results from an empirical investigation. *Corporate Reputation Review*, 13(4), 264-283. | Fictitious bicycle recall in Germany | Consumers | Consumers consider the organization as highly reputable before the crisis. | Consumers' perceptions of problem severity are not influenced. | Perceived Pre-crisis Reputation > $R_H$ | (Perceived Severity)$_t$ = (Perceived Severity)$_{t-1}$ |
| Feng, T., Keller, L. R., Wang, L., & Wang, Y. (2010). Product quality risk perceptions and decisions: Contaminated pet food and lead-painted toys. *Risk Analysis*, 30(10), 1572-1589. | Recalls of contaminated pet food and lead-painted toys in the United States | Consumers | Consumers have access to extensive news coverage on product recall. | Consumers overestimate the actual probability for potential adverse outcomes. | Received Media Coverage > $C_H$ | (Perceived Risk)$_t$ = (Perceived Risk)$_{t-1}$ + $c$ × Media Amplification |
| | | Consumers | Consumers obtain unpacked information on a recall event. | Consumers have an overall higher judged probability of quality risk. | Reception (Unpacked Information) = True | (Perceived Risk)$_t$ = (Perceived Risk)$_{t-1}$ + $c$ × Amplification (Unpacked Information) |
| Yannopoulou, N., Koronis, E., & Elliott, R. (2011). Media amplification of a brand crisis and its affect on brand trust. *Journal of Marketing Management*, | Yogurt recall in Greece | Consumers | Consumers have experiences with yogurt recall and have cumulative brand trust. | Consumers tend not to perceive higher risks associated with the recalled product. | Experience (Recall) = True Brand Trust > $T_H$ | (Perceived Risk)$_t$ = (Perceived Risk)$_{t-1}$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| 27(5-6), 530-546. | | Consumers | Consumers acquire risk information from mass media. | Consumers accept that the problem is 'general', 'important', and that particular 'risks' are associated with the brand. | Recall Portrayal (Consumers) = Recall Portrayal (Media) | (Perceived Risk)$_t$ = (Perceived Risk)$_{t-1}$ + $c$ × Media Amplification |
| Feng, T., Keller, L. R., Wang, L., & Wang, Y. (2010). Product quality risk perceptions and decisions: Contaminated pet food and lead-painted toys. *Risk Analysis*, 30(10), 1572-1589. | Recalls of contaminated pet food and lead-painted toys in the United States | Consumers | The organization launches product recall. | Consumers check websites most frequently for more information. | Recall = True | Probability (Consulting Websites) > Probability (Other Options) |
| Yannopoulou, N., Koronis, E., & Elliott, R. (2011). Media amplification of a brand crisis and its affect on brand trust. *Journal of Marketing Management*, 27(5-6), 530-546. | Yogurt recall in Greece | Consumers | Consumers have a low involvement with a low-cost disposable product. | Consumers do not discuss the incident with family, friends, or colleagues. | Involvement (A Low-cost Disposable Product) $< I_H$ | Interpersonal Communication = None |
| | | Consumers | The organization launches product recall. | Consumers interpret the associated risks through media discourse rather than rationally examining aspects of technical discourses. | Recall = True | Risk Interpretation (Consumers) = Risk Interpretation (Media) |
| | | Media | The organization launches product recall. | The media construct images of risk and fear in attracting the public interest and exploring the dimensions of the crisis. | Recall = True | Communicated Risk (Media)$_t$ = Communicated Risk (Media)$_{t-1}$ + $c$ × Media Amplification |
| Venugopal, P., Soni, A., Tiwari, R., & Gupta, S. (2012). Product recall: Effect on brand perception. *International Journals of Marketing and Technology*, 2(12), 199-208. | Dell laptop battery recall and Toyota car recall | Consumers | The organization launches product recall. | Consumers view a government press release as more objective than a company advertisement describing the recall. | Recall = True | Perceived Objectivity (A Government Press Release) > Perceived Objectivity (A Company Advertisement) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Consumers | The organization launches product recall. | Consumers view the print media as more trustworthy and somewhat more objective than the sound medium. | Recall = True | Perceived Reliability (Print Media) > Perceived Reliability (Sound Medium) |
| Bunniran, S., McCaffrey, D. J., Bentley, J. P., & Bouldin, A. S. (2009). Pharmaceutical product withdrawal: Attributions of blame and its impact on trust. *Research in Social and Administrative Pharmacy*, 5(3), 262-273. | Hypothetical pharmaceutical product market withdrawal | Consumers | The organization launches a pharmaceutical product withdrawal. | Consumers show low trust for insurance companies and Pharma but high trust for pharmacists and physicians. | Recall = True | Trust (Individuals) > Trust (Organizations) |
| Freedman, S., Kearney, M., & Lederman, M. (2012). Product recalls, imperfect information, and spillover effects: Lessons from the consumer response to the 2007 toy recalls. *Review of Economics and Statistics*, 94(2), 499-516. | 2004-2007 U.S. toy recalls | Consumers | The organization launches product recalls. | Consumers use the information contained in the recall announcements to update their expectations about the safety of other toys produced by the manufacturer. | Recall = True | Expectation (Other Products) = Expectation (Recalled Products) |
| Muralidharan, E. (2012). *Managing product recalls – Factors that influence recall restitution and time to recall*. Ph.D. The University of Manitoba. | Product recall | Consumers | Recall is due to the internal operations of the firm, and the severity of the recall is high. | Affected consumers receive lower restitution from the firm. | Cause (Internal Operations) = True  Severity (Recall) > $S_H$ | Restitution $_t$ = $c$ × Cause (Internal Operations) × Severity (Recall) |
| | | Organization | The organization considers the crisis as severe. | The organization issues product recall quickly. | Severity (Crisis) > $S_H$ | Time (Taken to Issue Recall) = $c$ × Severity (Crisis) |
| Umehara, E., & Ohta, T. (2011). Game of risk communications – The case of a Japanese carmaker. *IEEE Transactions* | Car recall | Organization | A guardian agent is present. | The carmaker discloses recall information. | Presence (A Guardian Agent) = True | Disclosure (Recall Information) = True |

| | | Organization | The carmaker forecasts that the probability that the user finds the fault information on the car increases to a certain degree. | The carmaker discloses recall information. | Probability (Finding Fault Information) > $P_H$ | Disclosure (Recall Information) = True |
|---|---|---|---|---|---|---|
| Hooker, N. H., Teratanavat, R. P., & Salin, V. (2005). Crisis management effectiveness indicators for US meat and poultry recalls. *Food Policy*, 30(1), 63-80. | U.S. meat and poultry recalls | Organization | The plants launch meat or poultry recalls. | The hazard type or severity does not influence recall effectiveness. | Recall (Meat or Poultry) = True | Effectiveness (Recall) = $c$ |
| | | Organization | The plants launch meat or poultry recalls. | Cases at large plants do not have shorter durations than cases at smaller plants. | Recall (Meat or Poultry) = True | Case Duration (Large Plants) $\geqslant$ Case Duration (Smaller Plants) |
| | | Organization | The plants have a very small size. | Recalls are more effective for very small plants compared to small plants both in terms of the recovery rate and the ratio of recovery rate to case duration. | Size (Plants) = Very Small | Recovery Rate (Very Small Plants) > Recovery Rate (Small Plants) <br> Recovery Rate / Case Duration (Very Small Plants) > Recovery Rate / Case Duration (Small Plants) |

# B Survey instrument

This instrument shows the complete questions included in the survey. The detailed account of the survey is covered in Chapter 6.

## SECTION I   Demographics

Q1. What is your gender?

❑ Male
❑ Female

Q2. What is your age?

❑ 20 or less
❑ Between 21 and 30
❑ Between 31 and 40
❑ Between 41 and 50
❑ Greater than 50

Q3. What is the highest level of education you have completed?

❑ Grade school
❑ High school
❑ Professional degree
❑ Bachelor's degree
❑ Master's degree
❑ Doctoral degree

Q4. Please estimate your total 2015 household income before taxes, combining income from all household members, from all sources:

❑ $10,000 or less
❑ $10,001 - $30,000
❑ $30,001 - $50,000
❑ $50,001 - $70,000
❑ $70,001 - $90,000
❑ $90,001 or more

Q5. Do you have children?

❑ Yes
❑ No

## SECTION II   Information sources

We would like you to think about an incident in which your current milk supplier, i.e. ABC Company, has had a contamination problem. There is a broken pipe in its processing factory, and this has allowed bacteria to accumulate and contaminate liquid milk sold to supermarkets. A small number of the bacteria can cause severe poisoning leading to respiratory and muscular problems in adults. The bacteria can also affect the intestinal system in infants. The company has issued a recall for all milk products to all its customers.

Q6. Which social sources of information about the      How many of these are there?
crisis would you consult?

❑ Friends                                                    _____

❑ Neighbours                                  _____

❑ Colleagues                                  _____

❑ Family members                            _____

❑ Other individuals in your Community     _____

❑ News media

(Newspapers and periodicals, Internet, TV, and radio, etc.)     _____

❑ Other, please specify                         _____

## SECTION III   Importance of different considerations

In this section we would like you to say how important different considerations are when you think about this issue. We are going to ask you to compare different pairs of consideration, and say how important they are relative to each other.

Q7. When you form your risk perception, how much relative importance would you give to your *own perception* and *other people's perceptions* respectively?

❑ 0%, 100%
❑ 10%, 90%
❑ 20%, 80%

- ❑ 30%, 70%
- ❑ 40%, 60%
- ❑ 50%, 50%
- ❑ 60%, 40%
- ❑ 70%, 30%
- ❑ 80%, 20%
- ❑ 90%,10 %
- ❑ 100%, 0%

Q8. It is possible that you could notice contamination yourself, for example through smell, or appearance of the milk. When you form your risk perception, how much relative importance would you give to *noticing contamination yourself* and *other people's perceptions*?

- ❑ 0%, 100%
- ❑ 10%, 90%
- ❑ 20%, 80%
- ❑ 30%, 70%
- ❑ 40%, 60%
- ❑ 50%, 50%
- ❑ 60%, 40%
- ❑ 70%, 30%
- ❑ 80%, 20%
- ❑ 90%,10 %
- ❑ 100%, 0%

Q9. When you form your risk perception, how much relative importance would you give to the *recall notice* compared with *other people's perceptions*?

- ❑ 0%, 100%
- ❑ 10%, 90%
- ❑ 20%, 80%
- ❑ 30%, 70%
- ❑ 40%, 60%
- ❑ 50%, 50%
- ❑ 60%, 40%
- ❑ 70%, 30%
- ❑ 80%, 20%
- ❑ 90%,10 %

❑ 100%, 0%

Q10. When you think about the effect of a recall on your **trust** in the producer, what is the relative importance you would give to *timing (whether the recall was early or late)* and *voluntariness (whether the producer made the recall voluntarily or involuntarily)*?

❑ 0%, 100%
❑ 10%, 90%
❑ 20%, 80%
❑ 30%, 70%
❑ 40%, 60%
❑ 50%, 50%
❑ 60%, 40%
❑ 70%, 30%
❑ 80%, 20%
❑ 90%,10 %
❑ 100%, 0%

Q11. When you form your risk perception, what is the relative importance you would give to your *feeling of trust in the producer* and *other people's perceptions*?

❑ 0%, 100%
❑ 10%, 90%
❑ 20%, 80%
❑ 30%, 70%
❑ 40%, 60%
❑ 50%, 50%
❑ 60%, 40%
❑ 70%, 30%
❑ 80%, 20%
❑ 90%,10 %
❑ 100%, 0%

Q12. When you form your risk perception, how much relative importance would you give to *media communicated risk* and *other people's perceptions*?

❑ 0%, 100%
❑ 10%, 90%
❑ 20%, 80%

- ❑ 30%, 70%
- ❑ 40%, 60%
- ❑ 50%, 50%
- ❑ 60%, 40%
- ❑ 70%, 30%
- ❑ 80%, 20%
- ❑ 90%,10 %
- ❑ 100%, 0%