The views of experts and the public regarding societal preferences for innovation in nanotechnology

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The views of experts and the public regarding societal preferences for innovation in nanotechnology

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To Ma, Pa, Mannu and Mannat

Contents

CHAPTER A

Abstract

Nanotechnology represents an emerging technology with varied application areas. It has been identified as the next scientific breakthrough with potential for positive impacts for society. The development and application of emerging technologies has been shown to be contingent upon societal responses to those technologies and their applications. Socio-psychological factors will potentially influence societal responses to nanotechnology, and play an important role in its development and commercialisation. The views of both experts and the general public regarding societal preferences for innovations in nanotechnology will be important in identifying which applications will be commercialised. If expert views regarding the determinants of societal acceptability do not align with those held by the general public, applications that consumers will reject may be introduced early in the commercialisation trajectory and focus public opinion on the negative aspects of nanotechnology. Conversely, applications which are acceptable to consumers may never be commercialised if experts perceive that consumers are likely to reject them. This thesis identifies and describes factors influencing societal response to nanotechnology by incorporating views from experts and the general public. Three research approaches were utilised. The first focussed on reviewing previous scientific research into the socio-psychological factors that influence public acceptance of new technologies. The second focussed on identifying and quantifying expert views on the factors that will influence societal acceptance or rejection of nanotechnology. The third tested whether the different factors do, in fact, drive public opinion.

The results show that, in the opinion of experts, perceived risks, perceived benefits and concerns about coming in contact with nanomaterials represented the most important factors shaping societal response. The general public identified perceived risks, benefits, need and socio-ethical concerns as important factors influencing the acceptability of different nanotechnology applications. Despite experts being able to identify many societal determinants of acceptance, the public raised additional issues, which stresses the importance of incorporating actual public concerns, and not just expert assessments, in the process of technology development. The views of experts and the general public did not align when discussing public acceptance of agri-food applications of nanotechnology. Experts believed that the public would reject nanotechnology applied to agriculture, which was not the case for consumers. At a time when innovations in nanotechnology are still developing and have not yet been fully commercialised, this thesis has provided insights into how different applications will be received by society, which in turn may provide information of relevance to formulating policy regarding future implementation and commercialisation trajectories for different types of nanotechnology application.

CHAPTER 1

General Introduction

Technological advances continue to contribute to the evolution of civilization. From the discovery of fire, the advent of agriculture to the more recent developments in gene technology, the quest for knowledge and the desire to improve quality of life has driven humanity to explore developments in science and apply those to human requirements and needs. Many of these technological breakthroughs have transformed society by introducing completely new social phenomena, and have had lasting effects on human values, power structures, ideas and acted as potential drivers of socioeconomic, political and institutional change (Crow and Sarewitz, 2001; Dolata, 2009; Shneiderman, 1998). New technologies have potential consequences for the way in which society is organised. However, societal responses to the technological innovations may in turn be driven by concerns about the impact of technology on societal and social structures and relationships (Frewer et al., 2004). Societal response determines to an important degree the success and failure of the market introduction of new technologies (Cameron, 2006; Frewer et al., 2004). As seen in past, public debate surrounding the controversial use of nuclear technology following the second world war (Chapin and Chapin, 1994; Gilbert, 2007; Van Der Pligt, 1985), application of synthetic pesticides in agriculture in the 1960's (Kroll, 2001; Pollock, 2001) or, in recent decades, concerns about using food irradiation (Bruhn, 1995; Fife-Schaw and Rowe, 1996) and genetic modification (Dale, 2004; Hall, 2007) have led to negative societal response which in turn have had negative consequences for their commercialisation. All these incidents have highlighted the importance of understanding societal response to new technologies. Failing to do so may slow down the progress of new technologies or lead to their rejection.

Nanotechnology is an emerging technology which potentially has impacts across many different sectors, from agriculture and food production, to medicine, electronics, biomaterials and energy production to name but a few. Some observers have noted that nanotechnology represents the new frontier of science and technology with unprecedented power to radically change our lives (Drexler, 2004). At the same time, it is acknowledged that agrifood and other applications of nanotechnology may be associated with similar societal concerns as those associated with genetic modification (Cushen et al., 2012; Mehta, 2004; Royal Society and the Royal Academy of Engineering, 2004). As a consequence, predicting societal responses to nanotechnology, how these differ between different areas of application, and what is driving these is important if effective regulation and exploitation of technology is to occur. The views of both experts and the general public regarding societal preferences for innovation in nanotechnology will be important in identifying factors influencing societal response to nanotechnology. Expert stakeholder views on societal responses to nanotechnology can help in predicting how expert views are likely to influence the development, implementation and commercialisation trajectory of nanotechnology. In the long term, it will be the public response towards different applications of nanotechnology that will be crucial in determining success or failure of nanotechnology.

This thesis examines factors that will influence societal response to nanotechnology, considering both expert and lay opinions regarding the factors what will drive societal acceptance of nanotechnology and its applications.

1.1 Nanotechnology: exploring the future with key stakeholders

Nanotechnology is a broad term used to represent combinations of processes, materials and applications that span physical, chemical, biological and electronic science and engineering fields involving manipulation of materials at a size range in the nanometer scale (Chaudhry et al., 2010). Nanomaterials have been considered as materials (Borm et al., 2006) with at least one dimension below 100 nm (Lövestam, 2010). In 2011, the European Commission recommended defining nanomaterials as “a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm” (EU, 2011). At this scale, in part because of larger surface/volume ratio, the physical, chemical and biological properties of materials can be fundamentally different from the properties of the same materials used at larger scale. These properties have allowed the development of exploitable portfolios of technologies leading to a choice of unique applications and products. At the same time, rapid advances in the field of nanotechnology have also raised concerns regarding possible exposure to nanomaterials from consumer products and their impact on health and environmental safety (Borm et al., 2006; Chaudhry et al., 2008; Handy et al., 2008; Klaine et al., 2008; Oberdörster et al., 2007; Wiesner et al., 2009). Societal responses to the different applications of nanotechnology may be driven by the underlying expectations and concerns regarding the impact of nanotechnology among different stakeholders.

The views of different stakeholders with interests in nanotechnology will not only contribute to the whole societal debate about the technology, but will also shape the developments and future commercialisation of nanotechnology. One way of comparing stakeholders is by grouping them into 2 groups depending on knowledge: an “expert group” and the “general public”. A broader definition of expert groups includes groups of people with relevant, specialised knowledge acquired through experience (Burgman et al., 2011; Evans, 2008). In this thesis, we adopt the working definition of an expert group as: "people who have gained specific expertise through their profession, or who are professionally involved on a regular basis in evaluating, developing and or managing production of nanotechnology" (adapted from Fischer et al, accepted). The expert group included people from academia, industry, government, NGOs, and the media. Exploring expert stakeholder views on societal responses to nanotechnology at an early stage of technology development can help in predicting how expert views are likely to influence the development, implementation and commercialisation trajectory of nanotechnology (Berube et al., 2011). Of great importance to societal acceptance of technologies is their public acceptance. It has been recognised that public perceptions of nanotechnology and its applications need to be taken into account, as successful implementation and application may be contingent on developing applications which are acceptable to society (Renn and Roco, 2006; Royal Society and the Royal Academy of Engineering, 2004). Given that nanotechnology is still evolving and "under construction", views from both experts and the general public will contribute to the identification of factors relevant to societal acceptance or rejection of nanotechnology.

It is also important to compare and contrast opinions between experts and the general public with interests in nanotechnology and its application as previous research on risk perception of new technologies has documented that scientifically trained experts tend to differ in their judgements of risk from the public. Scientific experts are shown to consider technical factors such as morbidity, and mortality associated with a specific risk, and take the probability of occurrence of a hazardous event into account when formulating opinions regarding acceptability of the risk. Lay people take account of psychological risk characteristics such as dread, fairness, freedom to take or avoid risk while forming opinion about risks, including those related to new technologies (Barke and Jenkins-Smith, 1993; Blok et al., 2008; Sjoberg, 1999; Webster et al., 2010). Differences in risk perception between lay people and experts have been observed for various domains, including toxicology (Kraus et al., 1992), global climate change (Lazo et al., 2000), aviation (Thomson et al., 2004), biotechnology (Savadori et al., 2004), Creutzfeldt-Jakob disease (CJD) and Bovine spongiform encephalopathy (BSE) (Raude et al., 2005) and flood risks (Siegrist and Gutscher, 2006). Rowe and Wright (2001) suggested that some of the findings of differences between lay people and expert risk judgement could be due to methodological weakness, with results confounded by socio-demographic factors such as age, gender, socio-economic status etc., that potentially influenced risk perception. Nevertheless, whatever differences remain between expert and lay perceptions of emerging technologies may influence the development of societal discourse about technologies and their implementation.

A case in point is genetically modified (GM) food. Much of the controversy associated with commercialisation of GM food can be attributed to the inability of regulatory bodies to take account of the concerns of the public. Regulators and industry failed to take account of public concerns during the risk assessment process (Frewer et al., 2004). Further, lack of disclosure and communication about the way in which decisions were made, and the evidence base for these, their potential risks and how the risks would be managed, led to a public atmosphere of distrust and suspicion of the motives of the stakeholders perceived to be active in promoting the technology, and also led to the susceptibility to mischaracterisations of the technologies and their risks and benefits (Sandler and Kay, 2006). One lesson from the GM foods controversy is that, in order to gain public acceptance of, and trust in, a potentially controversial emerging technology, it is important to *explicitly address* public concerns into the risk analysis process. In the case of nanotechnology, expert stakeholders will largely determine the development and commercialisation trajectory of nanotechnology. If their views do not align with those held by the public, it will result in the societal rejection of nanotechnology. Therefore, understanding how lay and expert views align, or differ will influence not only the development of effective communication about nanotechnology (and other controversial technologies), but can also be used to inform the final design of specific applications, and their order of entry into the market place (Frewer et al., 2013b).

The issue of technology acceptance, and factors influencing societal response to new technologies, have generated wide interests in the academia, particularly in the area of social and behavioural research (Sjöberg, 2002). Much of this research has focused on risk and (more recently) benefit perceptions, and associated attitudes, as these are believed to be the major factors influencing public acceptance (Alhakami and Slovic, 1994; Barnett et al., 2007; Costa-Font et al., 2008; Gaskell et al., 2004a; Knight and Warland, 2005; Poortinga and Pidgeon, 2006; Purvis-Roberts et al., 2007; Renn, 2006; Schulte et al., 2004; Sjöberg and Fromm, 2001; Slovic, 1996; Slovic et al., 1991). Research in psychology has focused on how individuals define risks, and understand the key factors influencing such processes (Ricci et al., 2006). The psychometric study of attitudes towards technological risks and benefits have explored the emotional basis of risk judgments (Fischhoff et al., 1978). More recently understanding of the influence of risk perception has become dominant in the area of governance and decision-making. Within this, the role of affect or emotional responses as a "heuristic" has been investigated as a potential determinant of risk perceptions and risk-related behaviour (Slovic et al., 2007, 2002). This "risk as feeling" perspective suggests that intuitions experienced at the moment of decision-making can play a vital role in the choice an individual eventually makes (Loewenstein et al., 2001). All of these studies imply that people's attitudes towards technological risks and benefits are influenced by risk dimensions that go beyond a cognitive evaluation of possible positive or negative consequences of a technology. For nanotechnology a comprehensive overview of such determinants is lacking however.

1.2 Scope and outline of the thesis

The central research question of this thesis is:

What factors influence societal responses to nanotechnology?

As there are currently few nanotechnology applications on the market, public experience with the technology is limited, and hence public opinion provided through survey methods may give an insufficient overview of important determinants. Therefore, to provide a better estimate of important issues three research approaches were explored Figure 1.1.

First, previous scientific work was reviewed to identify those factors influencing public acceptance of new technologies. This part of the thesis seeks an answer to the question:

Which socio-psychological factors of public acceptance of technology have been studied in the social science literature?

Chapter 2 (Gupta et al., 2012a), presents an overview of the socio-psychological determinants of relevance to understanding public acceptance of technologies. In this study, the literature is reviewed to identify the various factors influencing public acceptance of 10 (controversial) technologies are reviewed. Correspondence analysis was applied to identify whether particular socio-psychological determinants were more relevant to technologies with specific characteristics. Regional and temporal trends were also examined to determine how socio-psychological determinants reported in the literature have developed and changed over time and between different regions of the world.

Second, the factors which experts thought were relevant to the societal acceptance were investigated. The research question answered in chapter 3 & 4 is:

What factors identified by experts will influence societal responses to different applications of nanotechnology?

Chapter 3 (Gupta et al., 2012b), reports on an exploratory study using repertory grid methodology in which experts from North-West Europe compare different applications of nanotechnology and identify factors influencing societal acceptability. In chapter 4 (Gupta et al., 2013), the results of chapter 3 are validated using an international group of experts from North America, India, Europe, Australia, New Zealand and Singapore. Their views on societal response to applications of nanotechnology were investigated. In addition, greater in depth interpretation of expert views was conducted in terms of the position taken by the experts. Expert uncertainty regarding whether an issue was relevant to societal acceptance of nanotechnology, and uncertainty regarding their response, was also measured. This was because it is of interest to evaluate uncertainty associated with opinion potentially influential in determining government or industry policy. Third, research on public perception of nanotechnology was conducted to answer the following question:

What factors do the public consider important in influencing societal response to different applications of nanotechnology?

Chapter 5 reports the results of an exploratory study using repertory grid methodology on public perception on nanotechnology in the UK. Consumers compared different applications of nanotechnology and identify factors influencing societal response to nanotechnology. The research findings were compared with the repertory grid study conducted using the expert stakeholder group (chapter 3). Chapter 6 reports on a nationally representative consumer survey in the UK that examined consumer opinion on selected applications of nanotechnology and determined the importance of different attitudinal constructs and perceptions on acceptance of different agri-food applications of nanotechnology. Applications were selected based on expert-lay comparisons in the two repertory grid studies (chapter 3 & 5) to present a relevant range of differently perceived applications. The survey was based on insights from all preceding chapters, bringing together factors identified in the consumer repertory grid study (chapter 5), the literature review (chapter 2) and the expert studies (chapter 3 & 4) to allow for a comprehensive overview of public response.

Chapter 7 concludes the thesis. The overall conclusions and a general discussion of the results is provided. The discussion synthesises the research reported in the thesis on determinants of societal response to different applications of nanotechnology, taking due account of the (1) differences and agreement between experts and the public and, (2) differences between acceptance and determinants thereof of different nanotechnology applications.

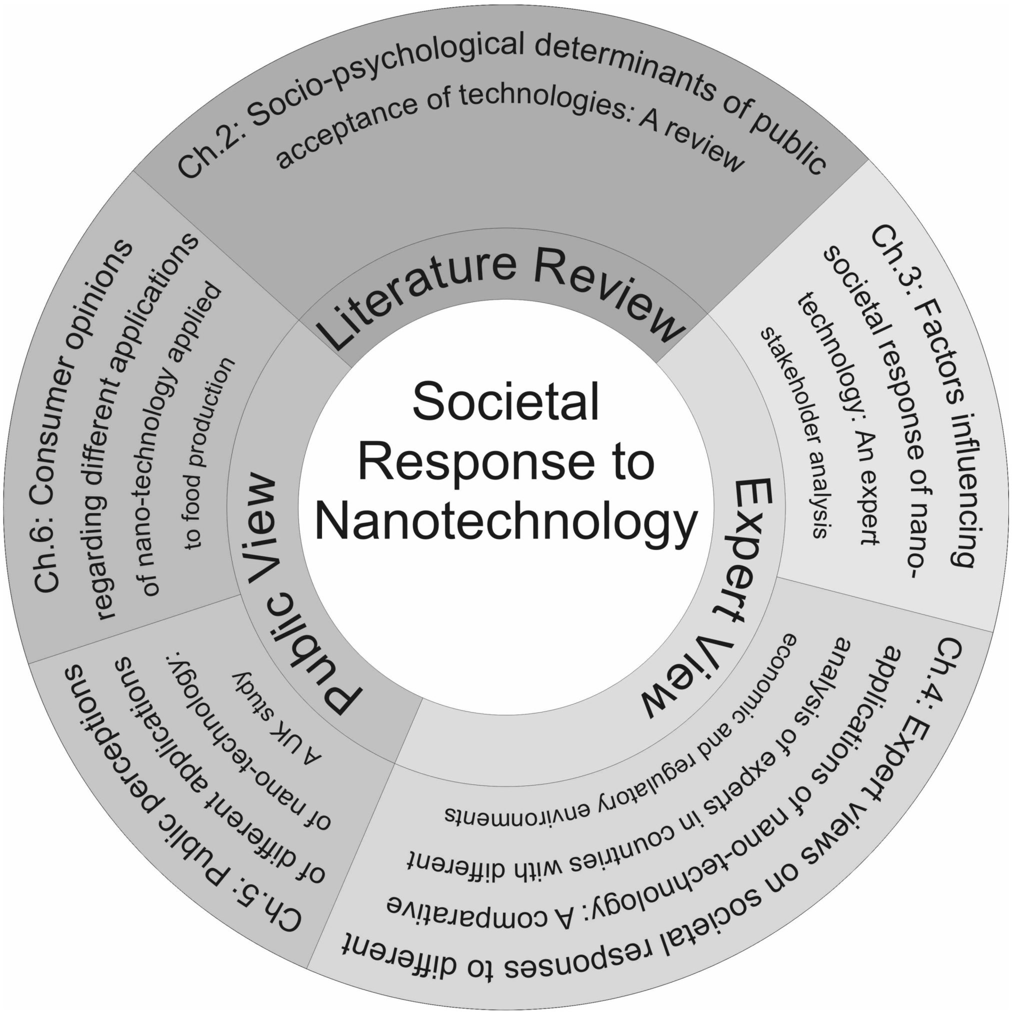

Figure 1.1. Schematic outline of the thesis

CHAPTER 2

Socio-psychological determinants of public acceptance of technologies: A review

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Abstract

Historically, many technologies have been associated with societal controversies, leading to public rejection of their use. It is therefore important to understand the psychological determinants of societal acceptance of emerging technologies. Socio-psychological determinants of public acceptance of 10 (controversial) technologies are reviewed. The results indicate that there has been an increased interest and focus on public acceptance of technologies in academia. Risk, trust, perceived benefit, knowledge, individual differences and attitude were found to have been a focus of research in 60% of articles. The results of correspondence analysis suggest that some determinants have been used more extensively in association with some technologies compared to others. As the published research has predominantly been conducted in Northern America and Europe, research across different cultural contexts internationally is required if globally relevant conclusions are to be reached. Implications for future research are discussed.

2.1 Introduction

Technology and Society

Technological advances are continuing to be part of the trajectory of evolving civilization. The quest for knowledge and scientific enquiry has driven humanity to explore developments in science and apply them to human requirements and needs. Technology has been defined as "a technological process, invention or method", or "the application of knowledge for practical ends" or "the sum of ways in which social groups provides themselves with the material objects of their civilization" (Random House Webster's College Dictionary, 1997). An example of the last is definition of technology provided by Mordini (2007) where technology is defined as a "social practice that embodies the capacity of societies to transform themselves by creating and manipulating not only physical objects, but also symbols and cultural forms". Considerable debate exists over the definition of technology and different approaches to technology (Markus and Robey, 1988; Orlikowski, 1992; Pfaffenberger, 1992; Woolgar, 1991). Social science studies of technology have included perspectives drawn from a large number of disciplines, including, for example, sociology, political science and economics (Williams and Edge, 1996; Pinch and Bijker, 1984; Otway and Von Winterfeldt, 1982; Klein and Kleinman, 2002). In the research presented here, the focus of the review is confined to social psychological approaches to understanding societal responses to technology.

Evident from the definition by Mordini (2007) is that sequentially evolving technologies are not isolated from the society in which they are embedded, but are integral to the social environment. Increased societal dependency on technologies necessitates the examination of "society-technology" interactions. In this context, it is important to note that on one hand a new technology may bring about radical changes in society, while on the other hand the fate of that technology rests with the society in which it is being applied. A negative societal response may be caused by the fact that, while many technologies deliver benefits to society, they may also introduce new risks (Gunter and Harris, 1998). As a consequence, such developments are often shaped by public controversies and concerns (Horst, 2005).

Public rejection of technologies has frequently resulted in negative consequences for the commercialization of technologies. In particular, unpredicted events and accidents affecting the public have acted as a signal which has resulted in fear and reluctance to adopt certain technologies, and resulted in consumer rejection of the products of these technologies. Perhaps as a consequence, much of the research focused on understanding societal acceptance of technologies been directed towards risk perception. As a case in point, the Three Mile Island accident sparked controversy and public negativity towards nuclear technology (Chapin and Chapin, 1994; Gilbert, 2007; Van Der Pligt, 1985). Another example is the market introduction of the first generation of genetically modified (GM) food crops, which led to polarized GM food debate internationally (Dale, 2004; Hall, 2007). The intensive societal discussion that followed was detrimental for the adoption and commercialization of GM crops and food products at least in some regions of the world (Aerni, 2005; Batrinou et al., 2005; Frewer et al., 2003; Klintman, 2002; Trait, 2001). Occurrence of such events and controversies over the use of technology, emphasize the importance of public acceptance in strategic development, application and commercialization of technologies.

Resistance to technologies and factors influencing public acceptance of technologies have generated wide interests in the academia, particularly in the arena of social and behavioural research (Sjöberg, 2002). A lot of research has been conducted on risk and (more recently) benefit perceptions and public attitudes as these are believed to be the major factors influencing public acceptance (Alhakami and Slovic, 1994; Barnett et al., 2007; Costa-Font et al., 2008; Gaskell et al., 2004a; Knight and Warland, 2005; Poortinga and Pidgeon, 2006; Purvis-Roberts et al., 2007; Renn, 2006; Schulte et al., 2004; Sjöberg and Fromm, 2001; Slovic, 1996; Slovic et al., 1991). Research in psychology focused on how individuals define risks and understanding the key factors influencing such processes (Ricci et al., 2006), and although originally most emphasis was on cognitive processes (e.g. Kahneman and Tversky, 1979), psychometric study of attitudes towards technological risks and benefits has explored the emotional basis of risk judgments (Fischhoff et al., 1978).

More recently the emotional approach of risk perception has become more dominant with the proposition of a theoretical framework that describes the importance of "affect-heuristic" in guiding risk perceptions and risk-related behaviour (Fischer and De Vries, 2008; Slovic et al., 2002, 2007), and the "risk as feeling" perspective suggests that intuitions experienced at the moment of decision-making can play a vital role in the choice an individual eventually makes (Loewenstein et al., 2001). All of these studies imply that people's attitude towards technological risks and benefits are influenced by risk dimensions that have little to do with the possible consequences of the technology. An individual can evaluate a risk cognitively and react to it emotionally. Pesticides, while considered to be the technology driving the "Green Revolution", and contributing to international improvement in food security, are primarily associated with consumer negativity linked to "negative affect", or emotional responses, rather than systematic cognitive evaluation of the issues, although these are also a topic of societal discourse (Alhakami and Slovic, 1994). Thus showing that cognitive evaluation and emotional response does not necessarily align. Although these two reactions are interrelated, they have different determinants. Exploring these determinants in detail can facilitate our understanding of the of the socio-psychological process affecting public acceptance of technology (Pin and Gutteling, 2009).

The aim of this study is to present an overview of the socio-psychological determinants of relevance to understanding public acceptance of technologies by analysing literature in social psychology and risk perception.

The main research question of the study is to identify which socio-psychological determinants of public acceptance of technology have been studied in the social science literature in the field of social psychology and risk perception. To do so the following sub-questions were addressed.

1. What potential socio-psychological determinants which influence public acceptance of technologies have been researched?
2. Are some socio-psychological determinants more relevant to specific technologies?
3. How have the socio-psychological determinants addressed in research of public acceptance of technology developed and changed over time?
4. Are there regional differences in determinants of public acceptance of technologies which have been researched?

2.2 Methods

The Database

A search was conducted using the Scopus (electronic) database in order to identify papers that included information about the determinants of public acceptance of technology. A first, scoping search was conducted to gain information about technologies that have been controversial or have raised discussion about their use. The second, main, search was conducted in order to identify papers focused on these technologies. The time scale for the search was between 1977 and 2008 (one paper of 2009 appeared online as a prepublication) and the last search was done on 12 November 2008. The search was limited to peer-reviewed articles and review papers and the subject area was confined to social science and psychology.

Duplicate articles, opinion papers, and articles which did not include relevant data were excluded from the main analysis. 292 research papers (Appendix A.1) were selected for the main analysis. 108 papers were excluded in the regional analysis as the country of data collection could not be identified for these papers, leaving 184 papers to be included in the regional analysis. The title, authors, abstract, keywords and bibliographical data of the articles were stored in Endnote. Although Scopus covers over 15,000 journals, a limitation of selecting publications from the Scopus database is that only articles cited in this database, and keywords assigned to the papers by its authors have been included in the review.

Selection of Technologies

The initial scoping exercise was done to quickly scan papers for selecting the technologies in the analysis. Search terms were developed to identify articles which focused on technology and societal controversy. Ten technologies were prominent (although not necessarily evenly distributed in occurrence with times). These were *nuclear technology, information and communication technology* (including computers and the internet), *mobile phones, chemicals used in agriculture* (pesticides and insecticides), *genetic modification, genomics, cloning, hydrogen technology, radio frequency identification technology* (RFID) and *nanotechnology*.

After the preliminary scanning, a literature search was conducted to collate papers addressing specific issues with regard to risk perception and its determinants for the selected technologies. The keywords used with each of the technologies were: technologies (as listed above) AND "scare OR fear" AND "controversy" AND "risk perception" AND "consumer acceptance OR consumer response OR consumer acceptability" AND "societal response OR societal acceptance OR societal concern OR social acceptability". In total 292 papers (Table 2.1) were found to be relevant, i.e. investigating determinants of social acceptance of technology.

Coding

The year of publication, research question, methodology, and the results were extracted from research articles. The factors influencing public acceptance were recorded from the research articles. These factors were coded into 31 different determinants of technology acceptance using thematic analysis. These were: *Impact (general, positive and negative); Expert versus lay knowledge; Affect (general, negative and positive); Impact health (positive and negative); Impact environment (positive and negative); Heuristics; Values (general and positive); Perceived risk; Perceived benefit; Perceived cost; Risk management; Risk* *assessment ; Attitudes (general, positive and negative); Ethics and values; Role of societal actors; Trust and culpability; Concern; Citizen knowledge; Individual differences; Communication; Costs*; and *Technology characteristics*.

Countries where data were collected were also coded for all the articles. In total, 39 countries were identified (including research that compared data from consumers in different countries or cultural contexts). These countries were then categorized into seven regions: North-Western Europe (UK, Germany, The Netherlands, Switzerland, Belgium, Sweden, Ireland, Norway, Austria, Finland, France, Poland and Denmark); Southern Europe (Romania, Turkey, Italy, Portugal and Spain); Northern America (USA and Canada); Latin America (Trinidad, Mexico and Argentina); Asia (Singapore, Korea, Hong Kong, Vietnam, Nepal, Bangladesh, Philippines, India, China, Kazakhstan, Malaysia, Japan and Taiwan); Oceania (Australia and New Zealand); and Africa.

Data Analysis

The content of the papers was analyzed on distribution of coded scores across year and region. In addition, correspondence analysis was used to investigate the relationship and trends across different determinants and technologies, to depict the results in categories on a few dimensions (Gurabardhi et al., 2004; Hoffman and Franke, 1986). To avoid determinants with very low frequencies distorting the analysis, the determinants that appeared only once were merged into super-ordinate categories (the role of societal actors positive and negative were merged into role of societal actors; risk management complete and incomplete were merged into risk management and risk assessment complete and incomplete were merged into risk assessment).

2.3 Results

Determinants influencing public acceptance of technologies

Thirty one potential determinants which emerged from the coding scheme were found to influence public acceptance of new technologies. More than one determinant was found to influence public acceptance in most of the articles. In terms of the technology that was the focus of the research, the most frequently investigated technology was genetic modification ($N = 104$). On an average an article includes between 1 and 2 determinants (Table 2.1).

Table 2.1. Distribution of articles and frequency of determinants over technologies

Technology	No. of Articles (out of 292)	Frequency of determinants (out of 558)	Ratio (No. of articles / Frequency of determinants)
Genetic Modification	104	210	2.02
Nuclear Power	49	99	2.02
ICT	45	93	2.07
Pesticides	30	50	1.67
Nanotechnology	16	30	1.87
Cloning	11	21	1.91
Mobile Phones	11	20	1.82
Hydrogen Power	7	11	1.57
Genomics	13	14	1.08
RFID	6	10	1.67

Of the 31 determinants, 6 determinants accounted for about 60% of all determinants mentioned across the sample. Of these, perceived *risk* was found to be the most frequently investigated determinant, and was reported 86 times. *Trust* was used 63 times; *perceived benefits* 51 times; *knowledge* 50 times; *individual differences* 44 times and *attitudes* 42 times. Other influential determinants were *negative affect* coded 27 times; *technology characteristics* and *role of societal actors* each coded 22 times. In the sample determinants like *negative impact general, positive impact general and positive attitude* were coded 12 times each and *ethics* and *cost* were coded 11 times. *Communication, negative health and environment impact* and *values* were found to be coded about 10 times. Less researched determinants were *expert versus lay knowledge,* *heuristics, perceived cost, risk management, negative attitude, general affect, concern* and *positive affect* (coded about 6 times each). Determinants that were coded the least number of times (1-2 times) were *positive environment impact, risk assessment, general impact, positive health impact* and *positive value*.

Correspondence analysis between technologies and determinants showed that certain determinants were associated more with specific technologies ($\chi^2 = 332.64$, $p = .006$; Figure 2.1). To classify these groups, hierarchical cluster analysis was applied to determine which technologies and determinants are associated more closely with each other. The four clusters identified in the cluster analysis comprised the technologies and the associated determinants. Clusters one and two came out as very clear clusters each including one technology, and one or more determinant. Cluster one showed the association of pesticides with the seven determinants *positive impact (health and environment), negative impact (health and environment), positive value, communication* and *cost.* The second cluster suggested that concern is associated with mobile phones. In cluster three, genomics and cloning appeared together with two determinants: *ethics* and *expert versus lay knowledge.* While these two determinants were associated strongly with cloning, they were weakly associated with genomics. In contrast to the first three clusters where a clear picture emerges for one single or two related technologies, the fourth cluster consisted of 6 technologies and 17 associated determinants. In this cluster nuclear technology and RFID were closely associated with *values,role of societal actors, impact general (positive and negative),risk management, perceived risk, attitude general, perceived cost* and *affect (general and negative)*. In the same cluster ICT, nanotechnology, hydrogen power and genetic modification exhibited close association with *attitude (positive and negative), technology characteristics, individual differences, trust, perceived benefits* and *knowledge*. While most of the determinants were found in the four clusters, some determinants were not found to have strong association with any of the technologies. These were: *heuristics, impact general, risk assessment* and *positive affect. Heuristics* and *impact general* were related to each other but they did not associate strongly with any of the technologies specifically.

Temporal trends in research on public acceptance of the technologies

An increase in the number of studies and determinants dealing with public acceptance of technologies occurred over time (Figure 2.2). A linear regression confirms an increase in publication over the years (F (1, 26) $= 52.22$,$p < 0.01$, $R^2 = 0.66$). Earlier publications focused on nuclear technology (first paper in 1977) and pesticides (first paper in 1988). In 1994 publications on genetic modification started appearing and the topic continues to attract scholarly

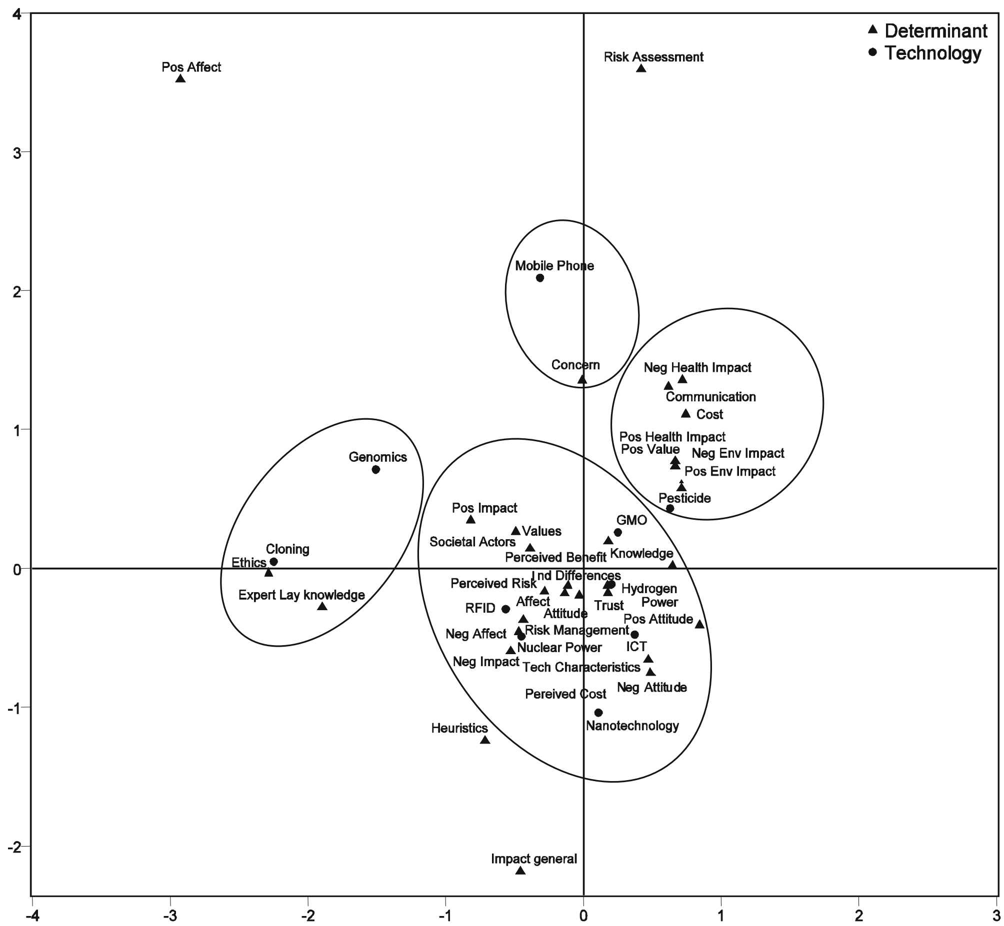

Figure 2.1. Results of the correspondence analysis of categorized determinants and technologies

attention, making it to be the most extensively researched upon technology. Research articles on hydrogen power, cloning, genomics and RFID were sporadic. Most recent in these technologies is nanotechnology, with papers being published in 2006, 2007 and 2008.

Over time, the number of determinants which have been investigated has increased (Figure 2.3), implying that research directed towards understanding public acceptance of technologies is becoming increasingly sophisticated. From Figure 2.3 we can see that the models used to predict public acceptance are getting more complex, with a wide coverage of determinants influencing technology acceptance. "Classical" determinants for example, *risk perception, benefit perception, trust, knowledge, attitude, negative impact and individual differences* continue to be included in research designs. In addition new determinants (such as *heuristics, concern, risk assessment, positive impact* and

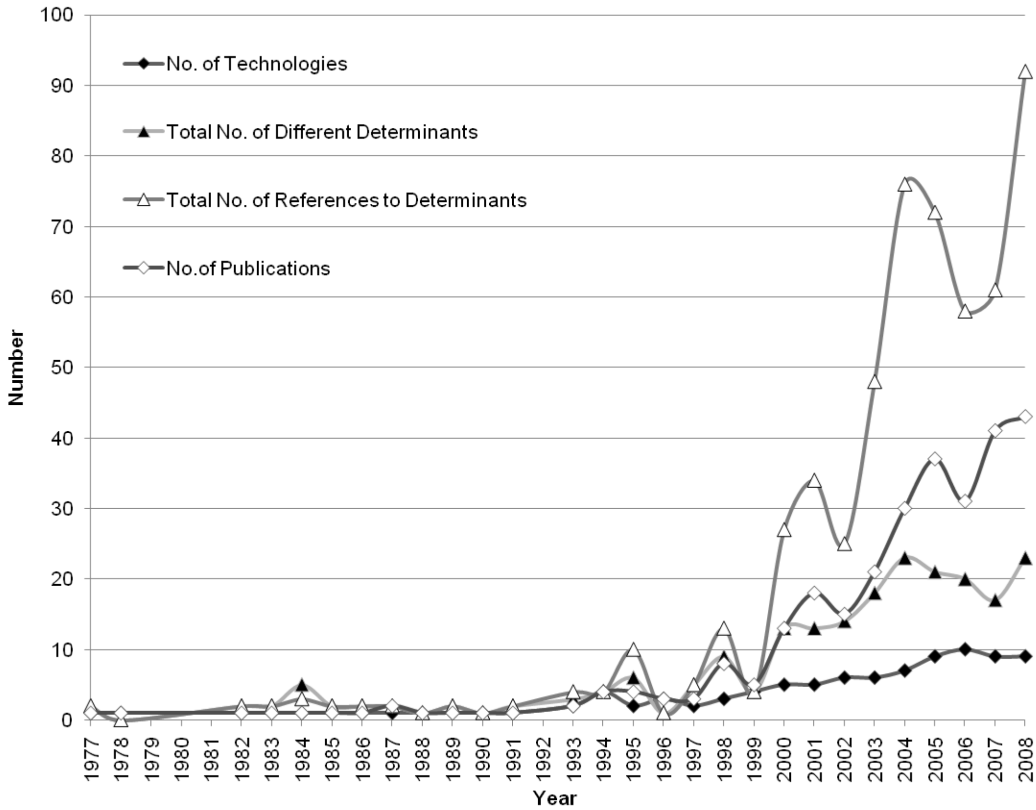

Figure 2.2. Trends over time (from 1977–2008) in number of publications ($N = 292$), technologies studied ($N = 10$), different determinants investigated ($N = 31$) and reference to determinants ($N = 558$) in the sample.

positive value) have been the topic of more recent research. In terms of risk and benefit perception, *perceived risk* was cited more often than *perceived benefit*, showing researcher prioritization of risk perception over and above benefit perception as an important determinant of consumer acceptance.

Regional trends in research on public acceptance

Regional trends in research on various determinants were examined for 184 research articles that included information that enabled the identification of country of collection (Table 2.2). Looking at the frequency of determinants investigated in different regions across the world, research originating in North West Europe investigated the greatest number of determinants (44%). This was followed by research originating in North America, (30%). Fewer determinants were investigated in research studies originating in Asia and Southern Europe, the least were reported for research originating in for Latin America and Oceania.

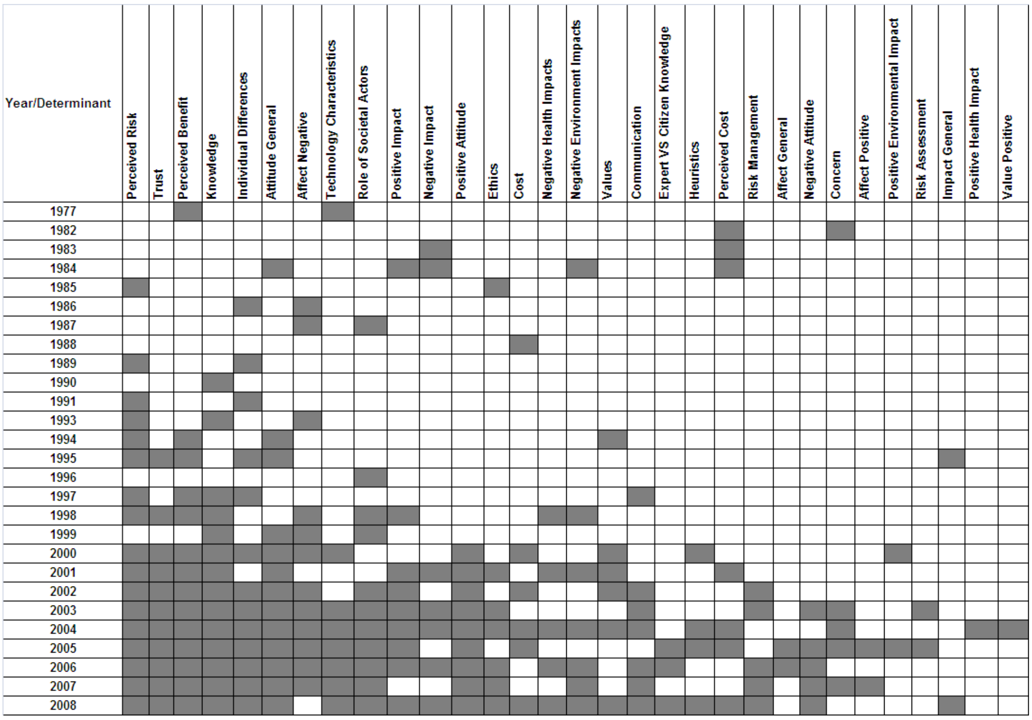

Figure 2.3. Coverage of determinants over the years (Each grey box refers to multiple occurrences of determinants in each year).

This sharp decline in frequency of determinants is, in part, attributable to fewer publications addressing few technologies in these regions. Of the 184 research articles, 19 articles were comparative, as data were collected in different countries or regions. However, these articles were again dominated by data originating in North-western Europe and Northern America.

2.4 Discussion and Conclusion

Public acceptance of technologies continues to be a focus of scholarly attention, as demonstrated by the steady rise in the number of publications and determinants investigated that are found to impact the acceptance. Regional trends show that most of the research has been carried out in North America and North-West Europe. While this may be in part, because the search was limited to the English language, it is nevertheless clear from this that most of this type of research is concentrated in the developed world. More research is needed in developing countries and countries with developing economies, to present a more comprehensive picture of societal response to new technologies.

Table 2.2. Regional distribution of articles and determinants on public acceptance

Region	Number of technologies covered	Number of determinants
North West Europe	10	29
North America	9	27
Asia	5	16
Southern Europe	5	18
Latin America	1	8
Africa	2	8
Oceania	3	9

Of the ten controversial technologies studied, research was most frequently focused on nuclear power, genetic modification and ICT compared to genomics, cloning, mobile phones and hydrogen power. The study of public acceptance of nanotechnology and RFID has only recently been initiated, in line with the recency of technological advances, and it is therefore too early to judge whether research into these technologies will provide major contributions to the technology acceptance literature. The publication trend for different technologies can be partly related to the year of their introduction or commercialization. Discussion about the consequences of using nuclear technology has been a topic of public debate since World War 2. Application of synthetic pesticides in agriculture drew public criticism in 1960's with the publication of Silent Spring by Rachel Carson, inspiring widespread public concerns associated with pesticide use and environmental pollution (Kroll, 2001; Pollock, 2001). The consequences of using genetic modification escalated the already existing public debate on the use of new technologies in 1994 with commercialization of genetically modified food crops and products. Ever since its introduction, the technology has been exposed to media attention and societal debate about its merits or otherwise (Bauer, 2002, 2007). Research focused on the application of cloning technology started appearing around 1997 when the first cloned higher animal "Dolly" (sheep) was developed (Bauer, 2002). An important point is that research into public acceptance of new technologies has tended to occur post- commercialization, when public concerns have begun to arise. In the case of nanotechnology, the discussion has been initiated at about the same time as the development of the technology, in response to concerns from developers about public negativity to its application. This indicates a shift in focus on public acceptance of technologies, from *post hoc* studies to a more proactive effort to identify public opinions and values prior to commercialization. The extent to which such information will be used to shape science strategy and specific application of nanotechnology remains to be evaluated.

Social science analysis focused on public acceptance of specific technologies is typically conducted after the technology has been introduced and commercialized, and subsequently been associated with societal disquiet or negativity. Thus, in the past, it would appear social science research funding has been allocated to those technologies which have become societally controversial. In order to better understand the process of technology acceptance in society, research into non-controversial technologies might be applied to identify what factors drive societal acceptance, (assuming that comparative analysis can be applied across technological areas, which are inherently associated with different levels of impact or political controversy). It would also resolve whether the inherently "dramatic" qualities of some technologies also drive researcher interest, which in turn drives funding cycles and societal discourse about the technologies in question.

It is recognized that the socio-political context in which technologies are embedded also shapes public debate and acceptance of these same technologies. Further discussion of this is beyond the scope of the current research study, as defined by the original research question. The question of why some technologies become societally controversial, whereas others do not, is worthy of further research.

The sophistication of the socio-psychological factors used to assess attitudes has also increased with time, reflecting theoretical advances in this area. *Perceived risk, perceived benefit, trust and culpability, knowledge, individual differences* and *attitude* are traditionally the most often reported or cited determinants; and these remain dominant. Temporal analysis of the data indicates that the postulated models explaining the public acceptance has increased in complexity, by adding, rather than replacing determinants. Determinants that were found to influence public acceptance of one technology contribute in shaping the acceptance for other technologies. The analysis has demonstrated that the number of social psychological determinants investigated in the context of technology acceptance has increased, perhaps reflecting theoretical advances in understanding public responses to technologies. Some determinants (for example, positive affect, risk assessment and heuristics) have been less frequently studied. A systematic critique of the relative predictive capacity of these different determinants is not currently available. A first step in the development of such a systematic review would be the simultaneous analysis of all potential determinants in a single study, or (possibly) through application of formal meta-analysis if appropriate data are available. This is a topic worthy of future investigation.

The temporal analysis has also confirmed that research that has focused on the individual as a "non-rational" actor has increased. This research suggests considerable support for the socio-psychological determinants of acceptance of technology underpinning lay opinion, as well as providing an explanation as to why these might differ from expert views. Further investigation into the disparity between lay and expert opinions of technology may systematically contrast the extent to which the different determinants predict technology acceptance in each group.

Certain determinants are seen to have more impact on public acceptance of specific technologies. Pesticides were mainly associated with health and environment, cloning and genomics, with ethics; while a large group of technologies was associated to most of the remaining determinants. This association between certain type of technologies and determinants to some extent can help us to understand and predict the factors that will set the stage for discussion of new and emerging technologies.

In this study paper a specific class of technologies has been investigated, that is, those technologies that have been enabling a myriad of applications with the potential to change society, as the impact of these applications ripples through society. These technologies can be called "transformative", as they have the power to transform society by introducing completely new social phenomena. Previous transformative technologies (agricultural technology, printing, aircrafts and vaccinations) have had lasting effects on human values, power structures and ideas and acted as potential drivers of socioeconomic, political and institutional change (Crow and Sarewitz, 2001; Dolata, 2009; Shneiderman, 1998). The emergence of the technologies reviewed in this paper not only fuelled the engines of economy and growth, but also raised critical issues of political and military influence (e.g. nuclear power), international competition (e.g. GMO), environmental crisis (e.g. pesticides) and ethical debates in relation to the discussions on the ethical acceptability of human control over and manipulation of nature (cloning and genomics), social changes resulting from expectations of being connected 24 hours a day, seven days a week (mobile phones) and protection of privacy (RFID, ICT).

Nanotechnology has the potential to become a transformative technology. It is among the recent emerging technologies which have been the focus of attention on the part of stakeholders, opinion leaders and media discussion. On one hand it presents unmatched opportunities to develop new products and services, and may result in longevity, public health benefits, and more sustainable production, but on the other raises concern, fear and anxiety among the public (Romig Jr et al., 2007; Schütz and Wiedemann, 2008; Siegrist et al., 2007b). Understanding the socio-psychological factors would allow contextualization of its development and implementation, and potentially facilitate allocation of resources in areas of application relevant to the wider needs of society (Renn and Roco, 2006; Roco, 2003).

Future research needs to explore the interrelationships between determinants, particularly those which have emerged as being influential in recent years, such as the relationship between perceived risk and benefit, but also identify the knowledge gaps and explore other psychological factors that have recently started appearing in the literature.

CHAPTER 3

Factors influencing societal response of nanotechnology: An expert stakeholder analysis

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Abstract

Nanotechnology can be described as an emerging technology and, as has been the case with other emerging technologies such as genetic modification, different socio-psychological factors will potentially influence societal responses to its development and application. These factors will play an important role in how nanotechnology is developed and commercialised. This article aims to identify expert opinion on factors influencing societal response to applications of nanotechnology. Structured interviews with experts on nanotechnology from North West Europe were conducted using repertory grid method in conjunction with generalized Procrustes analysis to examine the psychological constructs underlying societal uptake of 15 key applications of nanotechnology drawn from different areas (e.g. medicine, agriculture and environment, chemical, food, military, sports, and cosmetics). Based on expert judgement, the main factors influencing societal response to different applications of nanotechnology will be the extent to which applications are perceived to be beneficial, useful, and necessary, and how "real" and physically close to the end-user these applications are perceived to be by the public.

3.1 Introduction

Emerging applications of nanotechnology have the potential to deliver new manufacturing processes and products across various different sectors of application, ranging from agriculture to medicine to defence applications, which will potentially result in profound changes in society as a whole (Crow and Sarewitz, 2001). To realise the full potential of nanotechnology, significant resources have been allocated for nanotechnology research by government institutions, public and private research centres, universities and industry globally (Brossard et al., 2009; Roco, 2003; Roco and Bainbridge, 2005; Salerno et al., 2008). However, the potential social and economic benefits of nanotechnology may not be realised if the issue of societal acceptance of nanotechnology and the concrete products of its application, across a range of application domains, is not adequately addressed. In the past, societal responses to new technologies have played a crucial role in the success (e.g. mobile phones, internet) or failure (e.g. food irradiation; genetically modified foods in Europe) of such technologies (Frewer et al., 2011a; Van Kleef et al., 2010; Wright and Androuchko, 1996; Frewer et al., 2004; Gaskell et al., 1999). It is likely that, just as has been the case for some other new technologies, socio-psychological factors will influence the societal response to nanotechnology (Gupta et al., 2012a). It is recognised that such socio-psychological factors will shape the commercialisation trajectory of technology, but also facilitate allocation of resources in areas of application relevant to the wider needs of society. Thus the identification of these factors will play an important role in the future development of nanotechnology.

From the literature, there is some evidence that, at the present time, the general public has limited or no knowledge or awareness about nanotechnology, and that public involvement in the debate surrounding nanotechnology development is rare (Pidgeon et al., 2009; Priest, 2006; Ronteltap et al., 2011; Satterfield et al., 2009; Siegrist, 2008; Vandermoere et al., 2010). Therefore, at this stage in the development of nanotechnology, people with occupation related experience and expertise in nanotechnology from the scientific community, industry, policy makers or consumer representatives are likely to inform the development and application of nanotechnology.

An important element in determining how the technology will be implemented depends on the perceptions of these experts regarding societal acceptance of both the technology and its specific products across different domains of application. Although expert view on societal response to new technologies may not align with actual societal attitudes, (Barke and Jenkins-Smith, 1993; Flynn et al., 1993; Kraus et al., 1992; Sjoberg, 1999; Webster et al., 2010), those expert views on societal responses, are likely to influence technology implementation and commercialisation. Identifying expert priorities and preferences at an early stage of technological development can be used to identify how such views have influence on the commercialisation trajectory in the future. A study of these expert groups can provide an opportunity to examine which perceptions currently represent broadly shared consensus among the different stakeholder groups, and which are associated with a broader range of individual opinions (Besley et al., 2008). In addition research on expert views can provide a benchmark to analyse preferences and concerns, and may be used as a precursor to initiate dialogues at improving the practicality of regulatory actions (Berube et al., 2011). The present study can contribute to making future comparisons between public and expert views on societal issues related to nanotechnology as identification of the critical differences between expert and public opinion needs to be taken into account in framing risk communication efforts directed at public (Hagemann and Scholderer, 2009).

The aim of this study is to elicit expert opinion on factors influencing societal response to applications of nanotechnology. The specific objective of this study is to compare different applications of nanotechnology and identify expert views regarding factors influencing societal acceptability.

There have been some studies highlighting expert views on nanotechnology (Corley et al., 2009; Ho et al., 2011; Besley et al., 2008; Priest et al., 2010; Siegrist et al., 2007b; Yawson and Kuzma, 2010). Yawson & Kuzma (2010), showed that according to experts factors such as trust, institutions, risk and benefit perception and knowledge are likely to affect consumer acceptance of agrifood nanotechnology products. Siegrist et al. (2007b) used the psychometric paradigm to examine risk perception and the role of trust in developing attitudes toward nanotechnology among laypeople and experts. This study suggested that perceived dreadfulness of applications and trust in governmental agencies are important factors in determining risk perception. It also emphasised that for an expert sample in the study, confidence in governmental agencies was an important predictor of perceived risks associated with nanotechnology. Another study by Priest et al. (2010) compared the risk and benefit perception of nanotechnology among U.S citizens and a group of nanotechnology experts. The study showed that public opinion has started to diverge from expert opinion with respect to societal risks of nanotechnology as for citizens, there has been a rapid rise in concern over societal risks in comparison to risk associated with health and environment. A study on expert opinion on nanotechnology by Besley et al. (2008) showed that public health and environmental issues are the areas where both perceived risk and need for regulation are greatest. Also while considering risk and regulation, experts distinguished between health, environment and social risks. U.S. nano-scientist's risk and benefit perception of nanotechnology, as well as their support for nanotechnology regulation, showed that nano-scientists are more supportive of regulating nanotechnology when they perceive higher levels of risks. However, perceived benefits about nanotechnology do not significantly impact their support for nanotechnology regulation (Corley et al., 2009). Compared with the experts, the public judged nanotechnology as having greater risks and fewer benefits, and indicated less support for governmental funding of nanotechnology research (Ho et al., 2011).

Most previous research in this area has used a priori defined constructs, developed either from existing theoretical models which did not account for any specific concerns associated with public acceptance of the technology, or were decided by the researchers. To fully capture the factors that determine expert views on the societal response to nanotechnology, it would be advantageous not to make *a priori* assumptions about what expert consider to be important issues for societal acceptance (Frewer et al., 1997). Constructs elicited this way are likely to provide a more meaningful reflection of the real attitudes and perceptions of the group of participants being sampled (Henson et al., 2008). This, in turn, would help in evolving a more realistic picture of the potential factors driving societal response to nanotechnology and its applications. Repertory grid methodology in conjunction with generalized Procrustes analysis (GPA) offers a methodological solution. The repertory grid method (RGM) allows respondents to describe their response in their own words without imposing external, experimenter determined factors, while GPA allows the differentiation of constructs about which respondents agree, and the most important determinants can be identified (Frewer et al., 1997).

Elicitation of constructs is a complicated exercise, as too little structure makes the elicitation unfocused, while too much structure limits the depth of the results. Some structure can be provided by discussing specific applications of nanotechnology, instead of the technology as a whole. Until now, research on public perception of nanotechnology has largely focused on nanotechnology in general rather than specific applications (Cobb and Macoubrie, 2004; Gaskell et al., 2004a; Lee et al., 2005; Scheufele and Lewenstein, 2005), with the exception of few studies (Besley et al., 2008; Scheufele et al., 2007; Siegrist et al., 2007a,b; Stampfli et al., 2010; Yawson and Kuzma, 2010). Previous research has shown that the public perception of new technologies depends on the type of application domain as well as specific application attributes (Bauer, 2005; Frewer et al., 1997), emphasising the need to examine specific applications of nanotechnology within and between application domains (Pidgeon et al., 2009; Siegrist et al., 2007b).

To elicit constructs based on several different applications, the repertory grid method combined with generalised Procrustes analysis, provides structure and the basis for systematic comparative analysis on the one hand, whilst simultaneously allowing the elicitation of the required depth of arguments on the other. The RGM originated in psychology, and has been used in number of consumer research studies across different disciplines (such as medicine, health and food) to elicit individual's perception (Frewer et al., 1996, 1997; Lewith and Chan, 2002; Messina et al., 2008; Mireaux et al., 2007; Rowe et al., 2005; Russell and Cox, 2004; Tio et al., 2007). It can be used as a tool to facilitate a stakeholder dialogue on a societal issue (van de Kerkhof et al., 2009) and is particularly useful in consumer research in the early stages of product development (van Kleef et al., 2005). Advantages of using this particular method are: (1) It offers a structured method in exploring individual perceptions without imposing researcher bias or vocabulary (Mireaux et al., 2007; Schaffalitzky et al., 2009). (2) The method is efficient in identifying the full range of constructs that people use for evaluating an issue in a particular context with as few as 15 interviews (van de Kerkhof et al., 2009).

The data obtained using RGM can be analysed using generalised Procrustes analysis (GPA; Gower, 1975), a multivariate statistical technique that aims to identify consensus between observer assessment patterns and provide a measure of observer agreement with as little intervention of the researcher as possible (Wemelsfelder et al., 2000). By analyzing the results using GPA, variations due to assessors using different terms to describe the same stimuli and/or variation in their use of rating scales can be controlled (Mireaux et al., 2007).

3.2 Methods

Structured interviews with experts on nanotechnology from North West Europe were conducted using the repertory grid method. A list containing a broad range of different applications of nanotechnology was prepared. In order to maximise chances of finding relevant dimensions, the applications of nanotechnology were selected from different domains (cf. Siegrist et al., 2007b)). Following discussions with scientists directly involved in developing nanotechnology applications, the list was further developed and a final selection of 15 key applications of nanotechnology drawn from different areas (e.g. medicine, agriculture and environment, chemical, food, military, sports, and cosmetics) was made. These 15 applications of nanotechnology were then used to elicit the underlying constructs. A list of these applications is provided in Table 3.1.

Participants

A range of experts from North West Europe, who were engaged in diverse activities related to nanotechnology, were recruited into this study. An initial list of potential participants was compiled using the networks of the authors (Frewer et al., 2011b). In addition the names of potential participants were also compiled from open sources such as the list of participants from a conference on nanotechnology, and the authors of publications related to nanotechnology. From the initial list, a cross section of experts across the key stakeholder groups of academia, industry, government, media and consumer representative groups was invited to participate. Snowballing by asking participants to identify additional experts was used to complete the list. The response rate was 90%, resulting in 18 experts who agreed to take part in the study. One participant showed unwillingness to follow the protocol and the data provided by this participant was not further analysed, leaving 17 valid responses, 15 men and 2 women[1] (mean age $= 50.7$ years, $SD = \pm 7.1$ years) across all stakeholder groups (Table 3.2).

Design

The set of 15 applications was developed and refined in discussion with nanotechnology experts from the host institution of the authors. The survey used 10 triads compiled from a set of 15 specific applications of nanotechnology to start the elicitation of expert's opinion. Triads were presented in randomised order with each application being presented twice (in different triads) to each participant. For each triad, participants were asked, 'which 2 out of these applications of nanotechnology do you find to be similar in terms of societal response, and why?' and 'which of these application of nanotechnology is different from the other 2 applications in terms of societal response, and why?' to create bipolar arguments on differences between the applications. Once all 10 triads had been used to elicit arguments for societal response, or when no new arguments were elicited following presentation of 3 consecutive triads, experts scored each of the applications of nanotechnology on each of the arguments on a 5-point scale with personalised labelled end points derived from elicitation. Out of 17 participants, one participant could only use 9 triads to elicit arguments for societal response. The interview was prepared and piloted with 3 experts from the host institution, after which adjustments were made.

[1] Although an effort was made to have a gender balance in the sample, more male respondents agreed to participate in the study.

Table 3.1. Specific applications used in the generation of constructs about nanotechnology

1.	Targeted drug delivery by medically functionalized nanoparticles
2.	Neuro-implantable devices designed using carbon nanotubes used for simulating brain circuit activity
3.	Easy to clean surfaces made using nanomaterials, e.g. self-cleaning windows
4.	High-volume manufacture of very inexpensive RFID tags using nanoparticles
5.	Encapsulation and delivery of nutrients in food using nanomaterials
6.	Food packaging using nanoparticles with antimicrobial properties to increase shelf life of food products
7.	Smart pesticides developed using nanotechnology to enhance the effectiveness or delivery of pesticides
8.	Chemical sensors designed using nanomaterials (such as carbon nanotubes, zinc oxide or nanowires) to detect very small amounts of chemical vapours
9.	Membranes made of nanomaterials to build light weight and longer lasting fuel cells
10.	Remediation of contaminated water or soil using nanoparticles
11.	Development of efficient and cost effective water filtration processes by using nanomaterials (carbon nanotubes and nanoparticles)
12.	Smart-dust designed using nanotechnology for tracking changes in environment used in military intelligence
13.	Cosmetics containing nanoparticles used to enhance active ingredient absorption (e.g. sunscreens; anti-ageing creams), and facilitate repair damage (combat hair loss, prevent greying hair)
14.	Nanofabrication to get desired properties in the fabric such as making them antimicrobial, water and stain resistant, fire resistant or bulletproof
15.	Sturdy and better quality sports goods designed using nanomaterials e.g. golf clubs, tennis rackets, balls etc.

Table 3.2. Expert Groups

Expert Affiliation	Specific professional field
Academia	1. Biochemistry & Toxicology 2. Environment & Agriculture 3. Risk perception & Communication 4. Polymer technology 5. Material Science 6. Chemical Sensors
Industry	7. Medical 8. Food 9. Water filtration 10. Cosmetics 11. Polymer/Fabrics
Government/regulatory authorities	12. Ministry of Agriculture 13. Ministry of Defence 14. European Commission 15. Food Safety Authority
Consumer representative group	16. Consumers and nanotechnology
Media	17. Biotechnology Journalism

Procedure and data-collection

The data were collected in a face-to-face interview. The interview was divided into 2 phases. In the first phase, constructs describing determinants of societal response to nanotechnology were elicited, after which a small break was suggested. This was followed up by the second phase where the experts rated each of the applications on each construct they had personally described as relevant. Interviews were conducted using Idiogrid software (Grice, 2002). The interviews with experts were conducted between October 2010 to April 2011. Interviews were audiotaped after receiving verbal consent from the interviewee to allow more in-depth interpretation of expert opinions. On average it took 50 minutes to complete the interview. Interviewees received a token gift (worth about 10 Euro) as appreciation for their time.

Analysis

The aggregated data from the 17 experts consisted of 338 constructs in total. The number of constructs elicited from each expert ranged from 14 to 20, with the mean number of constructs being 18.2. The constructs were classified into series of construct-classes. Subsequently the initially defined construct-classes were applied to the constructs by a different researcher, after which modifications were made to the construct-classes. A final check of the emerging classification scheme was conducted by yet another researcher, who had not been involved in the classification until that time. When disagreement occurred, the classification was discussed until agreement was reached. The construct-classes were based on abstractions of the actual constructs; for example, if an expert stated that he or she found the applications "helpful for more people", this was deemed to fall within the class of "larger societal benefits". Some constructs were classified as combination of two construct-classes for e.g. "human health benefits + personal benefits". This process resulted in 58 construct-classes.

In order to check the classification conducted by the researchers, another member from the host institute, who was not involved in the research, was asked to conduct an independent coding of the constructs given by the experts, using the 58 construct-classes defined by the authors. A Cohen's kappa of 0.79 indicated good agreement between the coders regarding the classification of the constructs. Differences were then resolved by further discussion to achieve consensus on classification and in total 57 construct-classes were retained. The classified data were then analysed using GPA (Gower, 1975) and further interpretation was done using principal component analysis (PCA).

All the 17 grids from the experts were analysed using GPA. GPA considers each grid as a multidimensional geometric configuration, taking an expert's (classified) constructs as dimensions and the scores that the expert gave on these for each application as coordinates for the different applications. Each configuration has as many dimensions as it has constructs, and the 15 applications of nanotechnology are represented as points in this multidimensional space. The 17 configurations thus obtained are then matched to each other through a series of iterative mathematical transformations (rotation/reflection and scaling), while preserving inter-sample relationships within each configuration (Wemelsfelder et al., 2000). After convergence of the iterations, a 'consensus grid' is calculated by taking the mean of all transformed individual configurations. The match between the transformed individual grids and the consensus grid is expressed in terms of the "consensus proportion", providing the proportion of variance in the individual grids that is accounted for by the consensus grid (similar to R^2 in ordinary least squares regression analyses). It should be kept in mind however, that a perfect match (consensus proportion equal to 1) only implies that individual configurations can be aligned, but not necessarily that experts used the same constructs, nor that they rated the applications in the same way on similar constructs. That is, the obtained consensus grid is entirely independent of interpretive judgement by the researcher, is defined purely in terms of its geometrical properties, and has no semantic connotations attached to it. The match among individual grids in terms of semantic connotations will be assessed while interpreting more detailed results. The consensus proportion was tested for statistical significance using a randomisation test (Wakeling et al., 1992). In order to make further interpretation, the consensus grid was submitted to a principal component analysis (PCA) to extract the main dimensions (Grice and Assad, 2009). Finally, the principal components are interpreted by inspecting their relation with the 338 classified constructs.

Once the main factors influencing societal response to nanotechnology using GPA and PCA were identified, the transcribed interviews were reviewed to identify statements that supported expert views on regarding these factors explaining differences in expert views associated with the different applications of nanotechnology.

3.3 Results & Interpretation

The consensus proportion was found to be 0.60 indicating that the GPA consensus grid represented experts' judgements about the 15 applications with respect to their self-generated constructs fairly well. 1000 trials were generated based on the current data and showed that the observed consensus proportion was indeed significant ($p < .001$). Consensus proportion for only one expert was found to be 0.21, while for all the other experts it ranged from 0.46 to 0.72, indicating that there was relatively little variance in response with respect to the consensus grid. Consensus ratios for applications of nanotechnology ranged from 0.41 to 0.73 (Table 3.3). Higher consensus among expert views was found for applications like easy to clean surfaces, smart dust, encapsulation and delivery of nutrients in food, sports good, water filtration and medical applications of nanotechnology. More variation between experts opinion was found for applications such as nano fabric, fuel cells and food packaging.

Table 3.3. Consensus proportion for applications of nanotechnology from lowest to highest consensus proportion

Application	Consensus/Total
Nano fabric	0.41
Fuel cells	0.45
Food packaging	0.48
Chemical sensors	0.50
Smart pesticides	0.51
RFID tags	0.54
Cosmetics	0.55
Targeted drug delivery	0.61
Neuro-implantable devices	0.61
Water filtration	0.61
Soil water remediation	0.63
Sports goods	0.63
Encapsulation and delivery of nutrients in food	0.65
Smart dust	0.72
Easy to clean surfaces	0.73

The consensus grid obtained through GPA was subjected to PCA with Promax rotation. Examination of the scree plot suggests confining the interpretation of results to four principal components (PC) with the first six eigenvalues of the unrotated components being 3.92, 2.19, 1.62, 1.00, 0.39, and 0.24, explaining 87.3% of the total variance.

To interpret these four principal components (labelled PC1 through PC4) the structure loadings of each construct were calculated for each respondent. To summarise these loadings of 338 constructs on 4 components, a count was done for the number of high loadings ($\leq$ -0.50 or $\geq$ 0.50) for each construct-class on each principal component. Construct-classes that have at least 3 times a high loading on a component were deemed important for the interpretation of that component (highlighted in bold in Table 3.4). In addition, Figure 3.1 and 3.2 give plots of these loadings, providing the contours of the four main dimensions of the consensus grid that describes how experts as a whole perceived 15 applications of nanotechnology in terms of societal response.

The constructs used to describe determinants of societal response to different applications of nanotechnology on the positive end of PC1 are *"acceptable to society"*, *"environmental benefits"*, *"general benefits"*, *"perceived general benefits"*, *"human health benefits"*, *"larger socioeconomic benefits"*, *"consumer choice available"*, *"necessary"* and *"useful"*. Out of these construct-classes, "*larger socioeconomic benefits"*, *"necessary"* and *"useful"* are found to load only on PC1. This suggests that the first component is associated with the applications that are "**beneficial, useful and necessary**". The negative end of PC2 is associated with the constructs "*general benefits"*, *"environmental benefits"*, *"human health benefits"*, *"low general risk"*, *"outside body\food chain"*, *"perceived general benefits*" and "*acceptable to society*". Unlike PC1, PC2 has no unique construct-class, and is mainly found to address benefits and is therefore labelled as "**beneficial**". The third principal component (PC3) relates to "*acceptable to society"*, *"does not come in contact with public"*, *"environmental benefits"*, *"low general risk*" and "*outside body/food chain*". Of these construct-classes "*does not come in contact with public*" is only found to load on PC3. Hence, this component is primarily associated with "**distance from end user**". Finally, the fourth principal component (PC4) has its negative extreme associated with "*consumer choice available"*, *"perceived general benefits"*, *"personal benefits*" and *"real*", while the only construct found to load on its positive end was "*human health benefits*". The 2 construct-classes that load exclusively on PC4 are "*personal benefits*" and *"real*", therefore the fourth component can be characterised as applications that are "**real and personal benefits**".

Table 3.4. Total number of constructs in each construct-class and the number of constructs with a high loading on the first four principal components (PC)

Construct Class	PC 1 (33.05%)		PC 2 (30.36%)		PC 3 (25.55%)		PC 4 (19.49%)		Total
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	
Acceptable to society	**3**	0	0	**4**	**6**	0	0	2.5	15.5
Benefits for a subgroup of people in society	1	0	0	1	1	0	0	0	3
General benefits	**5.5**	0	0	**4.5**	2	0	1	2.5	15.5
Comes into contact with public	1	0	0	0	0	1	0	0.5	2.5
Consumer choice available	**3**	0	0	0	0	0	0	**4**	7
Developing country benefits	1	0	0	0	0	0	0	0	1
Does not come in contact with public	0	1	0	1	**4**	0	1	0	7
Easy to sell	1	0	0	0.5	0	0	0	0.5	2
Easy to understand	0	0	0	0	0	0	0	1	1
Environmental benefits	**5**	0	0.5	**5**	**7**	0	0	2.5	20
Ethical issues	1	0	0	0	0	0	0	0	1
Fiction	0	0	0	0	0	1	2	0	3
Human health benefits	**14.5**	0	0	**7.5**	1.5	0	**3**	2.5	29
Larger socioeconomic benefits	**6**	0	0	2	1	0	0	1	10
Less acceptable to society	0	0	0	0	0	1	0	0	1
Low general risk	0.5	0	0	**3**	**3.5**	0	0	2	9
Necessary	**7**	0	0	2	0	0	0	1	10

Continued on next page...

Table 3.4 – *Continued from previous page*

Construct Class	**PC 1 (33.05%)**		**PC 2 (30.36%)**		**PC 3 (25.55%)**		**PC 4 (19.49%)**		**Total**
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	
"Nice to have" applications	0	1	1	1	0	0	0	2	5
No concern	0	0	0	2	1	0	0	1	4
No environmental risk	0	2	0	1	1	0	0	0	4
No ethical issues	0	0	0	1	0	0	0	0	1
No health risk	1	0	0	0	0	0	0	0	1
No perceived risk	0	0	0	0	0.5	0	0	0.5	1
Not novel\no value addition	0	0	0	0	2	0	0	2	4
Not of immediate interest	0	0	0	0	1	0	0	0	1
Not scary	0	0	0	0	1.5	0	0	0	1.5
Novel application\value addition	2.5	0	0	0	0.5	0	0	0	3
Outside body\food chain	0	1	0	**3**	**6.5**	0	0	0.5	11
Perceived general benefits	**5**	0	0.5	**4**	1	0.5	0	**7**	18
Perceived general risk	0	0	0.5	0	0	0.5	0	0	1
Personal benefits	0	0	0.5	1.5	0	1	0	**4**	7
Process oriented	1	0	0	0	0	0	0	0	1
Real	0	0	0	0	0	0	0	**3**	3
Useful	**3**	0	0	2	2	1	1	2	11

Construct class coded as a combination of two different construct-classes was added as 0.5 to each of the classes separately allowing for decimals in the frequency count

A number of construct-classes were found that loaded on more than one principal component. This can be interpreted by taking into account the correlation between the components. That is, if two components are correlated then an association between construct-classes and one of these two components is likely to also imply a correlation between the construct-classes and the other component. As a high correlation is found between PC1 and PC2 (r = -0.51), most of the constructs that load on PC1 also load on PC2. There is no correlation between PC1 and PC3, and between PC1 and PC4. Similarly, there is no correlation between PC2 and PC3. There is moderate correlation found between PC3 and PC4 (r = -0.32), but they do not share any construct-class that has many high loadings on both these components.

If a construct-class has high loading on two different uncorrelated dimensions, this likely means that the construct-class was used differently across experts. Construct class for example "acceptable to society" is found to load on PC1, PC2 and PC3. The loadings on PC1 and PC2 can be interpreted as similar as they are highly correlated components (applications that are beneficial, useful and necessary will be acceptable to society). The interpretation for the uncorrelated PC1 and PC3 of the construct-class "acceptable to society" will be different as for PC1 acceptability to society seems to be used from the viewpoint of being beneficial, useful and necessary while for PC3 acceptability to society seems to be used from the viewpoint of not coming in direct contact with the public.

On the basis of the constructs associated with each principal component, it is possible to make some inferences about how experts have characterised the 15 applications of nanotechnology. Along PC1 (Figure 3.1), which is primarily associated with beneficial, useful and necessary – low/no benefits, low/no usefulness and less/not necessary continuum, applications such as targeted drug delivery, neuroimplantable devices, water filtration, soil-water remediation, chemical sensors and fuel cells are positioned positively. This indicates that these applications are associated with higher benefits and are deemed necessary and useful, as a consequence, will be more acceptable to society:

> "[The] *public would only* accept new things *if they really benefited from [them]*" (Industry, The Netherlands)

Applications such as smart pesticides, smart dust, RFID tags, nanofabrics, cosmetics and sports goods were rated less positively on this continuum, indicating these applications to be rated by experts as being perceived by society as less beneficial, less useful and less necessary:

> "*You do not need nanoparticles in cosmetics and food packaging*" (Academia, The Netherlands)

> "Sports goods are *nice to have but not necessary*" (Consumer representative group, UK)

Three applications were rated as neutral along this continuum. These were food packaging, encapsulation and delivery of nutrients in food and easy to clean surfaces. For these applications no clear consensus emerged in terms of benefits, usefulness, necessity and acceptability, for example an expert from industry explained:

> "*Research on Nano encapsulation is midway, if people feel it is all safe after safety evaluation, and people see that it has direct benefits for them, then they might accept them*" (Industry, Belgium)

> "*They [encapsulation and delivery of nutrients in food] have to be genuinely useful for people to accept such things*" (Consumer representative group, UK)

Of all the applications, smart dust was seen as unnecessary and least beneficial. The experts viewed targeted drug delivery and water filtration as the most beneficial and necessary applications of nanotechnology. All 17 experts agreed that targeted drug delivery was the most beneficial and necessary application of nanotechnology, and therefore will be the most societally acceptable application:

> "[The] *tendency of society is to accept medical applications more easily than other applications*" (Government/regulatory authorities, Belgium)

Water filtration, on the other hand, was seen as necessary and beneficial in particular in the context of developing countries:

> "*Fresh drinking water will be very difficult in third world countries and at that point we need such applications*" (Government/regulatory authorities, The Netherlands)

These application score similarly on PC2 that differentiates applications those are beneficial from applications that are less or not at all beneficial (Figure 3.1). On this high benefit- to low benefits continuum, applications such as smart pesticide, smart dust, food packaging, encapsulation and delivery of nutrients in food, RFID tags and cosmetics are positioned on the positive side, indicating that they are associated with fewer benefits and more risks, for example:

> "*People don't think about nanoparticles when it is in their [tennis] rackets and sports equipment, but they start to think of risks if these particles are in food*" (Industry, The Netherlands)

> "*For pesticides, I always use the same analogy with recombinant DNA technology – no benefits to consumers, only benefit[s] to producers; there it has no chance of better acceptance in the society*" (Industry, The Netherlands)

On the negative side of PC2 are the applications such as targeted drug delivery, water filtration, soil-water remediation, chemical sensors and fuel cells. These applications were seen as more beneficial with low risk, for example a governmental expert commented:

> "*Targeted drug delivery will bring direct benefits to the society*" (Government/regulatory authorities, Ireland)

Applications that remain neutral on this scale are nanofabrics, sports goods and easy to clean surfaces. Water filtration was rated as being the most beneficial. Smart dust was considered to be the least beneficial of all applications of nanotechnology:

> "*Smart dust is like you have sensors all around you, it is not at all positive*" (Industry, The Netherlands)

PC3 (Figure 3.2), corresponds to the distinction between applications that come in contact with public, little risky and less acceptable to applications that do not come in contact with public and therefore more acceptable, for example:

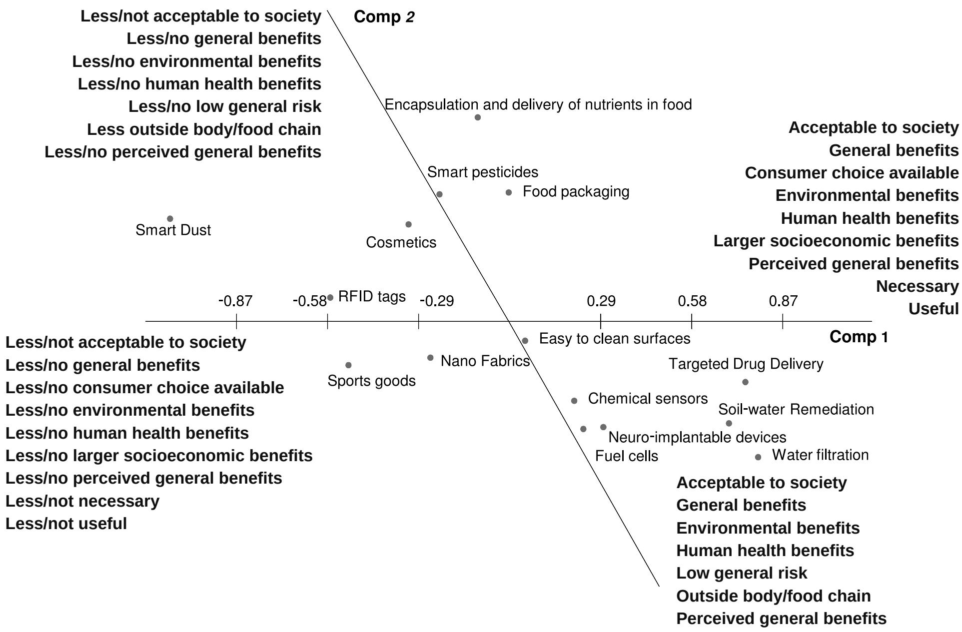

Figure 3.1. Location of applications of nanotechnology on first and second principal component

> "[The] *closer it gets inside the body, [the] more resistant people would become [to] it*" (Government/regulatory authorities, The Netherlands)

> "*In the beginning, to introduce the technology, it is better to start with membranes that do not come in contact with the public – first show everything is working without any problem*" (Industry, The Netherlands)

Applications located on the positive side of PC3 are RFID tags, soil-water remediation, water filtration, chemical sensors, fuels cells and easy to clean surfaces. These applications are considered as being more distant from end users.

> "*People will be able to see benefits in easy to clean surfaces as they [free nanoparticles] will not come in contact with the body*" (Academia, UK)

On the negative side of this dimension were applications such as smart dust, neuro-implantable devices, smart pesticides, encapsulation and delivery of nutrients in food, cosmetics and targeted drug delivery, which are described as less distant from the end user.

> *"If smart pesticides enter the body they have more chances of crossing over the cellular barriers and reach somewhere in the body that the conventional pesticides couldn't have reached"* (Academia, UK)

Food packaging, nanofabrics and sports good were rated as neutral applications on this continuum on PC3.

Finally, PC4 (Figure 3.2), differentiates between applications that are real and accrue personal benefits to the public from applications that appear less real with no/less personal benefits. Smart pesticide, smart dust and neuroimplantable devices are seen as less real, for example with regard to neuroimplantable devices an expert from industry commented:

> "*Neuroimplantable devices can be manipulated; it's kind of scary for people, something like a science fiction*" (Industry, Germany)

Experts rated sports goods, easy to clean surfaces, nanofabrics and cosmetics as applications that are more real, with more personal benefits. The remaining applications were ranked as neutral along PC4. These were RFID tags, soil water remediation, water filtration, chemical sensors, fuel cells, targeted drug delivery, food packaging and encapsulation and delivery of nutrients in food:

> "*RFID tags have slightly more distant business benefits, people might not care about it*" (Media, Germany)

3.4 Discussion

The present study investigated the views of the expert community regarding the potential societal responses to different applications of nanotechnology. Based on expert judgement, main factors influencing societal response to different applications of nanotechnology will be benefits, usefulness, necessity, issue of how close is an application from the end user, and how real these applications seem to be for them.

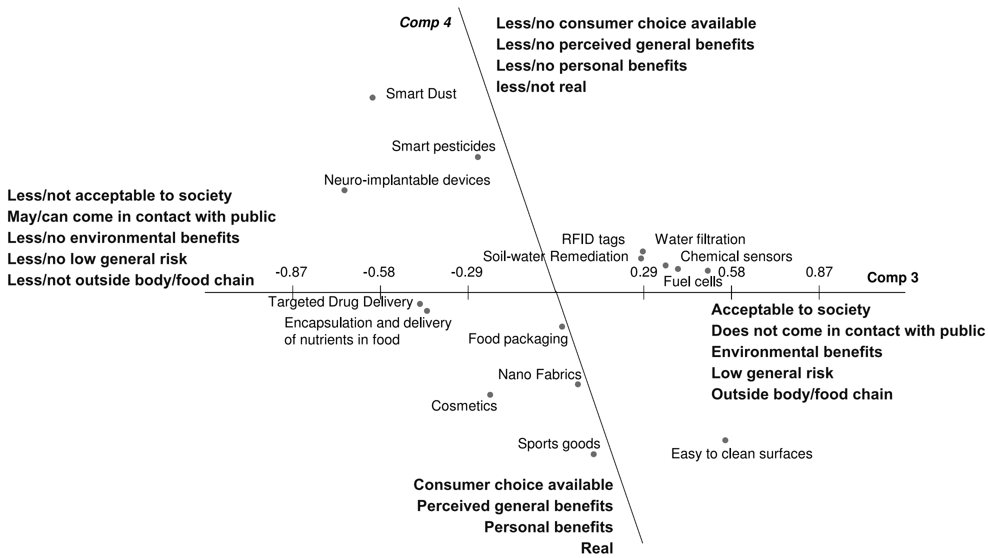

Figure 3.2. Location of applications of nanotechnology on third and fourth principal component

Benefits were generally mentioned by the experts included in this study before risk perception when discussing societal response. Risk perception is mainly mentioned as the opposite of benefit, rather than as a primary evaluative dimension. The present study shows that, according to experts, benefits will be the dominant factor that people would consider while making their choice for nano-products. Despite evidence that some people believe nanotechnology is riskier than do experts, many studies on public opinion on nanotechnology show that the public believes that benefits of nanotechnology will outweigh the risks (Burri and Bellucci, 2008; Priest and Greenhalgh, 2011; Satterfield et al., 2009; Scheufele and Lewenstein, 2005; Stampfli et al., 2010), in line with the perceptions of experts in the current study. In contrast, other researchers have emphasised that societal responses to nanotechnology are likely to focus on risk rather than benefits (Marchant et al., 2008; Ronteltap et al., 2011; Sheetz et al., 2005).

Medical application (targeted drug delivery) was rated as the most societally acceptable application of nanotechnology by experts. Application with environmental benefits such as water filtration, soil-water remediation, fuel cells, and chemical sensors were seen by experts to be the most beneficial applications of nanotechnology and likely to be societally acceptable. Nanotechnological innovations specifically in medical and environment domains have identified public perceptions of benefit and optimism regarding successful implementation (Besley et al., 2008; Burri and Bellucci, 2008; Priest and Greenhalgh, 2011).

In addition, the concept of need and usefulness has emerged as important construct-classes in the analysis. According to the expert community, public response to a particular application of nanotechnology will not just focus on perceived benefits alone but also emphasise on questions relating to whether that application is necessary or whether it is seen as "trivial" and whether an application is useful. For example, water filtration was seen as beneficial and the most necessary application, in particular in context to the developing countries. Similarly, targeted drug delivery was deemed necessary in treating illness. Applications such as sports goods and cosmetics were seen as "nice to have applications" but not necessary.

The notion of "distance from end user" also emerged as an important factor. According to experts, people will make their decisions about the acceptability of a particular use of technology by assessing the possibility of coming into contact with the nanomaterial, or the chances of migration of nanoparticles into the body or food chain. Therefore acceptability will not just depend on benefits but also be influenced by distance from end user. This particular factor may play an important role in shaping societal response to nanotechnology applications in the food domain; while the benefits associated with medical applications (for example, targeted drug delivery) are thought to be perceived to outweigh the risks. There is still no consensus on whether application of nanotechnology in food will be acceptable to society. For example, there is evidence to suggest that Swiss citizens were concerned about the migration of nanoparticles (Burri and Bellucci, 2008), in the body or environment. The food domain has been reported to be perceived differently to other domains in the US (e.g. energy-related and medical applications). A close link between acceptability and risk-benefit judgements associated with perceived "bodily invasiveness" was also observed (Conti et al., 2011). Research conducted in Switzerland has demonstrated that people perceive nanotechnology food packaging as more beneficial than foods processed using nanotechnology (Siegrist et al., 2007a, 2008b), while research done in France shows that people in France are pessimistic about both of these applications (Vandermoere et al., 2011). This highlights the need to take into account cross-cultural factors in determining acceptability, an issue not raised by the expert participants included in the study presented here.

The final factors that emerged from the analysis consist of the notion of realism and personal benefits. Experts were of the opinion that people will distinguish between applications on the basis of the personal advantages that would accrue to an individual, and how real or close to reality these applications will appear to the public.

The use of RGM in conjunction with GPA facilitated the elicitation of a number of constructs by experts without imposing researcher bias. However, to interpret the broad range of elicited constructs, coding the responses into fewer construct-classes is required. Although the methodologies have been developed to ensure a reliable coding scheme, this may have inadvertently introduced some researcher bias. An alternative approach may be to ask experts themselves to code the elicited constructs into construct-classes which are agreed upon by the entire group of experts, using a Delphi-like process (Frewer et al., 2011b).

The methodology used in this study facilitates identifying areas of consensus and similarities among the respondents. The differences among expert view could be either due to differences in opinion or due to uncertainties associated with the extent to which an individual expert is certain of the relevance of a particular construct to each application or application domain. These differences remain to be evaluated and future research is required in this direction. In addition, the present study provides a snapshot of expert opinions from North West Europe which may limit the geographical generalizability of the results. Future research should seek to compare responses of experts from different countries in order to present a complete overview on factors influencing societal response to nanotechnology. Finally, the elaboration of current research on "expert stakeholders" compared with the "lay public" is essential. The results presented here may contribute in making these future comparisons.

Fifteen out of 17 experts made direct comparisons between nanotechnology and genetic modification while discussing development of food applications and pesticides using nanotechnology. It has been noted that the experiences with genetically modified organisms and other controversial technologies have been linked with new technologies (including nanotechnology (Frewer et al., 2011a; Marchant et al., 2008)). This suggests that experts speculate that social negativity will arise as nanotechnology is commercialised, in particular within the agrifood sector, and that at this stage in implementation understanding *why* this occurred with genetic modification may be useful when determining how nanotechnology might be commercialised.

Finally, the views of experts regarding the extent to which different applications of nanotechnology will be societally acceptable are likely to determine how and when these different applications are commercialised. Many experts in the study sample were of the opinion that the introduction of nanotechnology might follow the same course as that of genetically modified organisms, unless a more societally relevant innovation trajectory were adopted, and this might explain why participants emphasized the role of perceived benefit in terms of societal acceptance of nanotechnology applications. Assuming that experts shape the process of innovation, one might anticipate that the first products introduced into the (European) market will be those which experts perceive will be viewed as most beneficial and least related to societally less acceptable application in, for example, the agrifood sector. If this is indeed the case, the success of such an approach in terms of societal acceptance of specific nanotechnology applications can be evaluated, and contrasted to the case of genetically modified food where the applications initially introduced were not perceived to be beneficial by the public.

It is of interest that societal perceptions of risk are less often taken into account as primary evaluative dimension in expert analyses of the factors determining societal acceptance, and this may reflect an expert bias towards identifying an optimal commercialisation strategy rather than one focused on the application of precautionary regulation or other measures aimed at extremely low risk levels; regardless of potential benefits lost to society as a whole, or individual end-users.

In addition, consumer decision-making may be differentially biased by perceptions of risk, and this effect may further depend on the area of application for example, risks associated with nanotechnology and food production may be weighted more heavily than those associated with medicine when consumer decisions about acceptability are made. Further research is needed in this regard.

3.5 Conclusions

The results of this study show that, according to nanotechnology experts, the general public will differentiate nanotechnology applications based on the extent to which they are beneficial, useful, necessary, real and to which the end-user is physically close with them. Risk is less often described by experts as a potential factor shaping societal acceptability. In part, this reflects expert opinions of how lessons from the commercialisation of genetic modification may inform market entry of products made through application of nanotechnology, and shape the associated commercialisation trajectory. It also reveals experts recognition that societal demand for concrete and necessary benefits will increase demand for specific products, and that a “consumer led” product development strategy is required. The lack of recognition of the primary role of perceived risk in societal decision-making suggests that stakeholders in commercialisation of nanotechnology may need to consider further how consumers make trade-offs between perceived risk and benefit, in particular in more controversial areas of application such as the agrifood sector.

CHAPTER 4

Expert views on societal responses to different applications of nanotechnology: A comparative analysis of experts in countries with different economic and regulatory environments

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Abstract

The introduction of different applications of nanotechnology will be informed by expert views regarding which (types of) application will be most societally acceptable. Previous research in Northern Europe has indicated that experts believe that various factors will be influential, predominant among these being public perceptions of benefit, need and consumer concern about contact with nanomaterials. These factors are thought by experts to differentiate societal acceptance and rejection of nanotechnology applications. This research utilises a larger sample of experts ($N = 67$) drawn from Northern America, Europe, Australasia, India and Singapore to examine differences in expert opinion regarding societal acceptance of different applications of nanotechnology within different technological environments, consumer cultures and regulatory regimes. Perceived risk and consumer concerns regarding contact with nano-particles are thought by all experts to drive rejection, and perceived benefits to influence acceptance, independent of country. Encapsulation and delivery of nutrients in food was thought to be the most likely to raise societal concerns, while targeted drug delivery was thought most likely to be accepted. Lack of differentiation between countries suggests that expert views regarding social acceptance may be homogenous, independent of local contextual factors.

4.1 Introduction

Historically, societal response to technologies and their applications has largely defined their success or failure Frewer et al. (2004). For example, public debate surrounding the controversial use of nuclear technology (Chapin and Chapin, 1994; Gilbert, 2007; Van Der Pligt, 1985), application of synthetic pesticides in agriculture (Kroll, 2001; Pollock, 2001) or, in recent decades, the consequences of using food irradiation (Bruhn, 1995; Fife-Schaw and Rowe, 1996) and genetic modification (Frewer et al., 2013b,a; Hall, 2007) have been associated with negative societal responses which, in turn, have had negative consequences for societal acceptance of products. Failing to integrate issues of societal preferences for development into technological commercialisation trajectories may slow down the progress of new technologies, or may even lead to rejection. Nanotechnology is one of the recent technological advancements that have already been incorporated into many industrial and consumer products across many different sectors, ranging from agriculture and food production, to medicine, electronics, biomaterials and energy production. Innovations in nanotechnology are occurring both in developed countries with established technology infrastructure and capacity, but also in emerging economies with high technology infrastructure and independent regulatory systems such as China, India and Brazil (Palmberg et al., 2009). Development and commercialisation of nanotechnology is expected to bring about changes in the commodities market, global production, value chains and scientific collaboration in developed as well as developing nations (Michelson, 2008). However, the full potential of advances in nanotechnology may only be realised if societal priorities for its development and application is taken into account (Macoubrie, 2006) at an early stage of technology or product development (Renn and Roco, 2006).

Expert stakeholder views regarding the societal acceptance of both the technology and its specific products across different domains of application will determine which products are commercialised, enter global market and in what sequence (Gupta et al., 2012b). Expert views regarding the societal desirability of nanotechnology applications are likely to be reflected in the public media. This has lead to the current emphasis on risks, benefits and product quality of food nanotechnology in the media (Dudo et al., 2011). Misapprehensions of experts about societal acceptability of specific applications of nanotechnology may have serious consequences for the commercial introduction and global trading of nano-enabled products. For example, experts may erroneously predict that a specific application is societally desirable, while the public may have concerns about the same product. This might easily result in the attempted commercialisation of products that trigger societal protest against nanotechnology as a whole. In contrast, experts may delay the commercialisation of products which in fact are deemed acceptable or desirable by the public because of perceived public concerns. For these reasons, understanding experts' *opinions regarding societal concerns* is important, not least because the order of entry of nanotechnology products into the marketplace will be contingent on expert evaluation of the likelihood of their potential success.

Expert stakeholder views regarding the societal acceptance of both the technology and its specific products across different domains of application will determine which products are commercialised, and in what sequence (Gupta et al., 2012b). Expert stakeholder groups can be defined by qualifications and experience, and include people with relevant, specialised knowledge acquired through professional activities (Burgman et al., 2011; Evans, 2008). This might include, for example, people with occupationally related experience and expertise in nanotechnology, drawn from the policy and scientific communities, industry, and or consumer representatives.

Differences between expert and lay evaluations of risk have frequently been identified in the literature. Empirical investigation has been conducted to explain differences between expert and lay perceptions of risk (Fischhoff et al., 1978, 1984; Slovic, 1987) and the results of this research has been used to explain why lay people may respond to risks in a different way than experts (Barke et al., 1997; Flynn et al., 1993; Savadori et al., 2004). However, people's attitudes towards emerging technologies and their applications may vary according to the perceived characteristics of both the technology and its applications. Social responses to one novel technology should not be assumed to represent a normative societal response to subsequent technological innovations (Frewer et al., 2011a). In fact, societal response to a specific technology may change in itself, for example in cases where societal drivers of technological need change or evolve, or if new drivers emerge (Frewer et al., 2013a,b).

However, until social acceptance data is formally taken into account during the process of technology development and commercialisation, experts will determine strategies for technology development, regulation and commercialisation. Gupta et al. (2012b) report that nanotechnology applied to food production may be potentially the most problematic area of application in terms of societal acceptance. This expert perception may have developed from events which were associated with societal rejection of GM applied to food production (e.g. see: Gaskell et al., 1999; Frewer et al., 2011a,b). There is, however, evidence to suggest consumer responses to the implementation of GM foods are not homogenous across different regions of the world, although data are incomplete in this respect (Frewer et al., 2013a,b). The negative societal response to GM foods is frequently regarded as the normative societal response to technological innovation in the agrifood sector, even in the absence of data relating to specific areas of technological application (Frewer et al., 2011a,b). Understanding the experts opinion on societal acceptance of agri-food applications of nanotechnology is therefore of particular interest.

Experts may, in turn, be influenced not only by local economic and regulatory conditions, but also local experiences of societal responses to preceding technologies, as it was the case with genetically modified (GM) foods, making it all the more relevant to compare expert opinions from different parts of the world.

Expert risk assessment of GM food has led to the emergence of different risk governance structures internationally (Table 4.1). Un-harmonised regulatory activities impeded the commercialisation strategy associated with technological innovation in a global market (e.g. see: Herrick, 2005; Vàzquez-Salat et al., 2012). For example, countries such as US and Canada adopted a more promotional stance towards GM regulation (Paarlberg, 2002), whereas the European Commission adopted a more precautionary approach (Nelson et al., 2001), including mandatory labelling of GM food products (Andrée, 2002; Carter and Gruère, 2003; Knight et al., 2008; Prakash and Kollman, 2003) which had international trade implications (Knight et al., 2008; Paarlberg, 2002). Countries such as Australia and New Zealand also imposed strict regulations concerning GM food, adopting one of the most stringent food safety regimes in the world outside of the EU (Andersen and Jackson, 2005). Trade implications and the threat of being denied access to highly lucrative developed country markets largely shaped developing countries' approach to GMOs (Shaffer, 2008). Moreover, when setting up their own regulatory frameworks, most of these countries tend to choose between US or EU approaches (e.g. India and Singapore). The development of different local or regional regulatory frameworks is likely to reflect differences in local or regional expert debate about regulatory issues. Expert views may reflect relevant local discourse, concerns and priorities associated with previous introduction of technologies applied to food production, which is then also bought to bear on the question of whether, and how, to utilise nano-technological advances in agri-food production.

Table 4.1. Different socio-economic and regulatory environment

	European Union	U.S.A	Australasia	New Zealand	India	Singapore
Estimated Population in millions (2011)	502.5[a]	310.5[c]	22.62[d]	4.40[d]	1,241.49[d]	5.2[d]
GDP per capita(2011)	$35,116[b]	$48,112[d]	$60,979[d]	$36,254[d]	$1,489[d]	$46,241[d]
Economy	- Internal market - World's largest economy	- Mixed economy - Second largest overall economy - World's largest trading nation	- Capitalist economy - One of the largest capitalist economies in the world	- Market economy	- Market based economy - G-20 major economies - One of the fastest-growing economies in the world	- Free market economy - Most business friendly economy
Free trade agreements	Chile, Korea, Mexico & South Africa	Australia, Bahrain, Chile, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, Israel, Jordan, Morocco, Canada, Mexico, Oman, Peru & Singapore	ASEAN, Chile, New Zealand, Thailand & U.S	ASEAN, Thailand, Chile, Singapore, Brunei & China	ASEAN, Bangladesh, Bhutan, the Maldives, Nepal, Pakistan, Sri Lanka, Afghanistan, Singapore, Thailand, Malaysia, Japan & South Korea	ASEAN, Australia, China, Jordan & India

Continued on next page...

Table 4.1 – *Continued from previous page*

	European Union	U.S.A	Australasia	New Zealand	India	Singapore
GMO Commercialisation	- GM maize grown in 6 EU countries - GM potato (2 EU countries)	Corn, cotton, soybeans, canola, squash, and papaya	- Grows GM cotton, canola, and carnations - Moratoriums implemented by South Australia and Tasmania	- Do not grow GM food - GM pine trees and brassicas (Field trials) - Imported foods with genetically modified components are sold	- Currently only grows GM cotton - Developed GM Eggplant (not available in the market yet)	- Do not grow GM food, but imports food (GM) from US
GMO Legislation	Regulations 1829/2003 and 1830/2003 of the European Parliament	- Federal Plant Pest Act (FPPA) - Federal Food, Drug, and Cosmetic Act(FFDCA) - Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) - Toxic Substances Control Act (TSCA)	Gene Technology Act 2000	Hazardous Substances and New Organisms (HSNO) Act 1996	- Indian Environment Protection Act - Recombinant DNA Safety Guidelines (1990) - Revised Guidelines for Research in Transgenic Plants - Guidelines for Toxicity and Allergenicity Evaluation of Transgenic Seeds, Plants and Plant Parts, (1998)	No legislations specific for GM regulation
GM Labelling	Mandatory labelling	Voluntary labelling	Mandatory labelling	Mandatory labelling	Mandatory labelling for packaged food	No labelling restrictions

[a] Eurostat, Statistics in Focus, 38/2011, "Population grows in twenty EU Member State; [b] International Monetary Fund; [c] US census bureau; [d] World Bank

The comparison between the societal concerns surrounding GM foods and nanotechnology applied to food production has been frequently made (see inter alia te Kulve et al., 2013; Thompson, 2011; Kuzma and Priest, 2010). First, both represent enabling, but "invisible" technologies (David and Thompson, 2011; Mehta, 2004). There are however, also differences between the introduction of foods produced using GM and nanotechnology. For example, the introduction of GM was associated with farmers and primary producers being initially targeted by the end-users of genetic modification. The acceptance of the resultant foods by consumers was not considered as relevant to the commercialisation trajectory. In the case of nanotechnology, it is not the primary producers who are regarded as the most relevant in the process of acceptable commercialisation (Sparling, 2011). This is demonstrated by greater public engagement in the development of nanotechnology making rejection less likely and the analogies with GM imperfect (Sandler and Kay, 2006). Nevertheless, if experts develop implementation strategies for different applications of nanotechnology which do not take account of societal concerns, successful application may be problematic. Examples include the extent to which consumers perceive products and applications to be unnatural (Thompson, 2011), and the extent to which the public perceive there is a lack of control and uncertainty about future consequences of technology application (Macnaghten, 2011). For example, research in the US shows that citizens may use religious or ethical argumentation to develop their judgements about the acceptability (or otherwise) of nanotechnology applications (Ho et al., 2011). In contrast, subject experts base their evaluations on their trust in the scientific process.

In the research reported here, experts are asked to report on their opinions regarding what they think of the societal response to different applications of nanotechnology. Experts were also asked to assess the uncertainty they perceived to be indicated with their opinions regarding different drivers of societal responses, together with the importance of these drivers. The more certain experts are about the relevance and relative importance of a particular societal determinant of response, the more likely the determinant may be in influencing their subsequent actions in prioritising commercialisation of different applications of nanotechnology.

Understanding expert views regarding factors influencing the acceptance of technological innovation, and the extent, to which these vary according to local socio-economic factors, is important when considering the introduction of novel technologies, in particular where these have implications for international issues such as global trade and trans-boundary environmental impacts.

Previous research into expert opinion has tended to utilise experts in specific regional or geographic locations. However, as the GM debate has shown, different expert discourses in different locations may contribute to the development of unharmonised regulatory structures in different regions and countries (Vàzquez-Salat et al., 2012). Differences in expert opinion may reflect local societal concerns about technology implementation (Frewer et al., 2013b,a). If it is assumed that experts base their opinions about the societal introduction to nanotechnology, at least in part, on their local experiences with the societal introduction of GM, it is important to identify differences in opinion between experts located in different regions, and allow a transparent and open global discussion to evolve in order to achieve consensus on harmonised innovation policy. Experts may differentiate between different types of risks, and the extent to which society in general needs to consider these in regulation and product assessment. For example, Besley et al. (2008) reported that US experts distinguish between health and environmental risks (where regulation needs to be prioritised) and social risks when considering risk and regulation associated with nanotechnology. Other studies of expert opinion regarding the societal acceptance of nanotechnology have suggested that social trust (i.e. citizens' trust in those institutions responsible for optimising consumer and environmental protection) may also determine societal acceptance of emerging technologies, including nanotechnology (Siegrist et al., 2007b; Yawson and Kuzma, 2010). Gupta et al. (2012b) conducted an expert stakeholder study to identify those factors that experts thought would influence societal response to different applications of nanotechnology. The methodology adopted in the study allowed the experts to express salient issues in their own words. Based on expert judgement, the main factors influencing societal response to different applications of nanotechnology were identified as the extent to which applications are perceived to be beneficial, useful, and necessary, and how "real" and physically close to the end-user these applications are perceived to be by the public. In contrast to other studies of factors influencing public acceptance, risk did *not* emerge as a primary evaluative factor influencing societal response to nanotechnology. Experts included in this earlier study were all from North-West Europe (and thus all exposed to similar experiences associated with the European GM debate and the regulatory and economic environment). However, comparisons with other countries with different regulatory and economic environments would contribute evidence that is salient to the development of a global development and implementation strategy for nanotechnology. The research extends that reported in chapter 3 (Gupta et al., 2012b) in two regards. First, in chapter 3 a European expert population was used based exclusively in North Western Europe, (thus their opinions regarding societal acceptance would be contextualised by EU policy and knowledge of societal responses to previous emerging technologies). Here, experts from 5 different regions of the world, with different regulatory regimes regarding technological innovation, are sampled and compared using survey methodology.

Second, in the research reported in chapter 3, the potential (psychological) determinants which experts thought would influence consumer uptake of different applications of nanotechnology were identified utilising repertory grid methodology. The study was therefore limited insomuch as inclusion of comparative international expert samples was not applied, no assessment of expert uncertainties regarding the relevance of the different issues was made, and the relative importance as perceived by experts regarding the drivers of societal acceptance of different applications was not addressed. While there is a body of research regarding on what factors experts perceive to be influential regarding societal responses to different applications of nanotechnology, there is little information regarding which factors are weighed the most in their decisions. There is therefore a need to assess the extent to which experts consider an issue important in determining societal acceptance, as well as the extent to which they are certain regarding its direction of impact or salience. Uncertainty may, for example, potentially contribute to delays in commercialisation or have impacts on policy development regarding implementation. In the current study, the use of survey methodology has allowed these issues to be analysed, albeit with the domain of agri-food nanotechnology which was judged to be the most societally controversial area of application by the experts participating in the research reported in chapter 3. Given that nanotechnology is still evolving and "under construction", it is often characterised by both social and scientific uncertainties. Therefore, there is a need to assess the extent to which experts are certain about whether an issue is important in determining societal acceptance and their own uncertainty regarding their opinion regarding its direction of impact or salience. The present study extends research in this area by examining expert views on the determinants of public acceptance of different applications of nanotechnology, where experts are drawn from in countries with different economic and regulatory environments. The present study addresses the following research questions:

1. To what extent do experts agree that specific social responses will shape the development and commercialisation of different nanotechnology applications?

2. How certain are experts that a particular issue/factor is relevant to societal acceptance?

3. Is there uncertainty associated with expert opinions regarding the relevance of the determinants of societal acceptance which have been identified?

4. Are there differences in expert opinion according to local variations in regulations and previous experience with technology acceptance?

4.2 Method

Participants & Data collection

For pragmatic reasons, only countries or regulatory regions where expert communities were likely to be fluent in English were included. This also avoided problem in validity associated with translation of survey questions (See: Steenkamp and Baumgartner, 1998). Experts from the different countries or regulatory areas were identified. A comprehensive list of potential participants from academia, industry, government, media and consumer representative groups was developed using the network of the authors, and using open sources such as the list of participants from conferences on nanotechnology and the authors of public domain publications related to nanotechnology. These experts were then invited by email to participate in the study and were requested to fill out an online questionnaire designed and administered using Qualtrics software. "Snowballing", a technique where participants were asked to identify additional experts for inclusion in the study, was used to identify further experts for inclusion. This method has been demonstrated to be effective in other studies of stakeholder opinion (Frewer et al., 2011b). Data were collected between March and August, 2012. On average, the questionnaire took about one hour to complete. A total of 67 experts of the 205 invited took part in the survey (response rate 32%). This is reasonable when compared to other studies involving experts (Frewer et al., 2011b). The final sample consisted of experts from Northern America ($N = 12$); Europe ($N = 21$); India ($N = 12$); Singapore ($N = 11$) and Australasia ($N = 11$). Thirty three per cent ($N = 22$) of the participants were women. Fifty four percent ($N = 36$) of the participants were aged between 35 to 54 years; 32% ($N = 21$) were between 55–74 years; 5% ($N = 3$) between 26–34 years; 3% ($N = 2$) between 18-24 and 1 participant was over 75 years. Four participants did not provide information about their gender or age. 62 out of 67 experts included information about their occupation, of which 60% ($N = 37$) were from academia or research institutes; 26% ($N = 16$) from government or regulatory authorities; 11% ($N = 7$) from industry and 3% ($N = 2$) from NGOs.

Questionnaire/measures

Factors influencing societal response to nanotechnology & certainty of expert response

Five nanotechnology applications, differentiated by expert opinion in terms of future acceptance, were selected for this study (Gupta et al., 2012b). These included*targeted drug delivery; smart pesticides developed using nanotechnology* *to enhance the effectiveness or delivery of pesticides; encapsulation and delivery of nutrients in food (Nanoencapsulated-food); food packaging using nanoparticles with antimicrobial properties to increase shelf life of food products; and development of efficient and cost effective water filtration process by using nanomaterials (water filtration).* For each application, the experts were asked to predict societal responses associated with one of the five factors: perceived benefit, perceived risk; necessity, consumer concern over coming into contact with nanomaterials, and the time frame for commercialisation of the nano product.

Scores for each nanotechnology application on each of the factors were collected on a 5 point scale. For example, perceived societal benefit was measured by asking 'how *beneficial* would an average member of the public in your country perceive (*followed by description of nanotechnology application*)' on a 5 point scale, anchored by 1 = extremely beneficial to 5 = not at all beneficial. An additional option of "no opinion" was added to the question. Participants were also asked to rate "how certain you are about your response" for each response on a 5 point scale, anchored by 1 = extremely certain to 5 = uncertain. The importance of each of the 5 factors regarding the societal introduction of nanotechnology was measured using a 5 point scale (anchored by 1 = agree strongly to 5 = disagree strongly). An overview of all items is provided in the Appendix A.2.

4.3 Results

Expert assessment of perceptions of societal benefits

Eleven experts (5 from Europe; 1 each from Northern America and Singapore and 2 each from Australasia and India) selected the "no opinion" option for at least 1of 5 applications, leaving 56 valid responses. A repeated measures ANOVA indicated significant differences across the five applications $F(3.35,\ 171.15)$[1] $= 16.56$; $p < .01$. Pairwise comparison between nanotechnology applications indicated that targeted drug delivery and water filtration were predicted to be perceived as the most beneficial applications of nanotechnology to society, followed by smart pesticides and food packaging. Nanotechnology application in food was rated as the least likely to be perceived by society as beneficial (Table 4.2). There was no difference across the region on perceived societal benefits $F(4,\ 51) = 1.46$; $p = .22$. However there was a significant interaction between societal benefits associated with different applications and region ($F(13.42,171.15) = 2.73$; $p < .01$). Pairwise comparisons (LSD) showed that the interaction effect was

[1] Because of the specific calculations used for repeated measures ANOVA, degrees of freedom for the F-test are estimated, allowing for degrees of freedom with decimals.

attributable to experts from Europe scoring *smart pesticide* as being perceived as relatively less beneficial by society compared to experts from Northern America and India. Experts from India, Singapore and Northern America predicted that *nano-encapsulated food* would be perceived as more socially beneficial compared to experts from Australasia. Experts from India and Europe predicted *water filtration* using nanotechnology as being perceived as more beneficial by society as compared to Australasian experts (Table 4.3).

A repeated measures ANOVA indicated a significant main effect of application influencing the self-rated certainty of expert's responses, ($F(3.22,\ 164.35) = 3.90$; $p < .01$). However, there was no significant main effect attributable to region, ($F(4,\ 51 = 0.49$; $p = .73$), nor was there an interaction between the certainty of expert's response for different applications across different countries ($F(12.89,\ 164.35) = 0.63$; $p = .19$). Pairwise comparisons (LSD) between applications show that experts were less certain in their opinions regarding the societally perceived benefits of *smart pesticides compared to* other applications (Table 4.2).

Table 4.2. Comparison of nanotechnology applications on different factors: estimated marginal mean scores (standard errors) based on repeated measure ANOVA

		Targeted drug delivery[1]	**Smart pesticide**[1]	**Nano - encapsulated food**[1]	**Food packaging**[1]	**Water filtration**[1]	**Test between categories**
Benefit[2]	perception	2.41^{a} (0.114)	2.95^{b} (0.113)	3.37^{c} (0.137)	3.01^{b} (0.122)	2.59^{a} (0.111)	$F(3.35, 171.15) = 16.56$; $p < .01$
	Certainty	2.50^{a} (0.103)	2.97^{b} (0.107)	2.71^{a} (0.098)	2.74^{ab} (0.113)	2.70^{a} (0.111)	$F\ (3.22, 164.35) = 3.90$; $p < .01$
Risk[3]	Risk	3.55^{a} (0.142)	3.11^{b} (0.177)	2.94^{b} (0.195)	3.48^{a} (0.207)	3.54^{a} (0.195)	$F\ (3.62, 177.43) = 7.07$; $p < .01$
	Certainty	2.71^{ab} (0.088)	2.84^{b} (0.118)	2.54^{a} (0.106)	2.68^{ab} (0.118)	2.85^{b} (0.123)	$F\ (3.81, 187.15) = 2.47$; $p < .05$
Necessity[4]	Necessity	2.96^{a} (0.142)	3.58^{b} (0.136)	3.90^{c} (0.137)	3.58^{b} (0.106)	3.14^{a} (0.145)	$F\ (3.27, 147.45) = 13.01$; $p < .01$
	Certainty	2.77 (0.117)	2.93 (0.103)	2.65 (0.118)	2.76 (0.119)	2.71 (0.114)	$F\ (3.29, 148.27) = 1.54$; p $= .19$
Physical contact with end user[5]	Concern	3.59^{a} (0.126)	2.96^{b} (0.122)	3.06^{b} (0.123)	3.50^{a} (0.129)	3.48^{a} (0.130)	$F\ (3.27, 147.45) = 13.01$; $p < .01$
	Certainty	2.83 (0.096)	2.29 (0.093)	2.75 (0.099)	2.75 (0.105)	2.85 (0.101)	$F\ (3.29, 148.27) = 1.54$; p $= .19$

Continued on next page...

Table 4.2 – *Continued from previous page*

		Targeted drug delivery[1]	**Smart pesticide**[1]	**Nano - encapsulated food**[1]	**Food packaging**[1]	**Water filtration**[1]	**Test between categories**
Timeframe[6]	Timeframe	3.36^{a} (0.140)	3.26^{a} (0.111)	3.15^{a} (0.147)	2.64^{b} (0.159)	2.73^{b} (0.158)	$F\ (5.22, 139.11) = 7.61$; $p < .01$
	Certainty	2.78^{a} (0.106)	3.29^{b} (0.092)	3.04^{c} (0.120)	2.93^{ac} (0.144)	2.94^{ac} (0.124)	$F\ (3.63, 149.07) = 5.26$; $p < .01$

1. Means sharing a superscript character are not significantly different between applications. Analysis is based on estimated marginal means using pairwise comparisons (LSD) to compare different applications ($\alpha = 0.05$)
2. High score is least benefit perception
3. High score is least risk perception
4. High score is least necessity perception
5. High score is least worried about coming into contact with nanomaterials
6. High score is longer time for an application to reach the market

Table 4.3. International comparison of risk & benefit perception of nanotechnology applications: estimated marginal mean scores (standard errors) based on pairwise comparison of simple effect

		Europe[1]	**North America**[1]	**Australasia**[1]	**India**[1]	**Singapore**[1]
Benefit $F(13.42,171.15) = 2.73;\ p < .01$	Targeted drug delivery	2.19^{a} (0.209)	2.09^{a} (0.252)	2.56^{a} (0.278)	2.40^{a} (0.264)	2.80^{a} (0.264)
	Smart pesticide	3.44^{a} (0.207)	2.73^{b} (0.250)	2.89^{ab} (0.277)	2.50^{b} (0.262)	3.20^{ab} (0.262)
	Nano - encapsulated food	3.50^{ab} (0.251)	3.09^{a} (0.303)	4.33^{b} (0.335)	3.10^{a} (0.317)	2.80^{a} (0.317)
	Food packaging	3.00^{a} (0.223)	2.82^{a} (0.269)	3.33^{a} (0.297)	2.90^{a} (0.282)	3.00^{a} (0.282)
	Water filtration	2.19^{a} (0.203)	2.55^{ab} (0.244)	3.22^{b} (0.270)	2.40^{a} (0.256)	2.60^{ab} (0.256)
Risk $F(14.48,177.43) = 2.00;\ p < .05$	Targeted drug delivery	3.47^{a} (0.192)	3.27^{a} (0.239)	3.56^{a} (0.265)	4.00^{a} (0.281)	3.44^{a} (0.265)
	Smart pesticide	2.82^{a} (0.224)	2.91^{ab} (0.278)	2.89^{ab} (0.308)	3.25^{ab} (0.326)	3.67^{ab} (0.308)
	Nano - encapsulated food	2.65^{a} (0.214)	3.00^{ab} (0.265)	2.00^{a} (0.293)	3.63^{a} (0.311)	3.44^{a} (0.293)
	Food packaging	3.35^{a} (0.226)	3.64^{a} (0.281)	3.11^{a} (0.310)	3.88^{a} (0.329)	3.44^{a} (0.310)
	Water filtration	4.00^{a} (0.220)	3.36^{ab} (0.273)	3.11^{b} (0.302)	3.88^{ab} (0.321)	3.33^{ab} (0.302)

[1] Means associated with the same superscript character are not significantly different between countries for an application. Analysis is based on estimated marginal means using pairwise comparisons (LSD) to compare simple effect of countries ($\alpha = 0.05$)

Expert predictions of perceptions of societal risks

Thirteen experts (4 from India; 4 from Europe; 2 each from Australasia and Singapore and 1 from Northern America) selected the "no opinion" option for at least one of five applications, leaving 54 valid responses. A repeated measures ANOVA indicated significant differences across the five applications, $F(3.62,177.43) = 7.07;\ p < .01$. Pairwise comparison between applications showed that *nano-encapsulated food* and *smart pesticides* were predicted to be perceived as more risky by the society compared to *food packaging*, *water filtration* and *targeted drug delivery* (Table 4.2). There was no difference across the region on societal risk $F(4,49) = 2.17$; $p = .09$, however there was a significant interaction effect between societal risk of different applications and different countries, $F(14.48,177.43) = 2.00$; $p < .05$ (Table 4.3). Pairwise comparisons (LSD) indicated that European experts scored *smart pesticides* as being perceived as relatively more risky by society than those from Singapore and higher for *nano-encapsulated food* than experts from India and Singapore. Similarly, experts from Australasia predicted *nano-encapsulated food* to be perceived as riskier by society than experts from Northern America, India and Singapore. Significant differences in predicted societally perceived risk for *water filtration* were observed between European and Australasian experts, where the former predicted the application being perceived to be less risky compared to the latter.

A repeated measures ANOVA indicated a significant main effect of application influencing the self-rated certainty of expert's responses, ($F(3.81,187.15) = 2.47$; $p < .05$). However, there was no significant main effect attributable to region, ($F(4,49) = 0.58$; $p = .67$) nor was there an interaction effect between the certainty of expert's response associated with different nanotechnology applications across different countries, ($F(15.27,187.15) = 0.77$; $p = .71$). Pairwise comparisons (LSD) between applications show that experts were less certain in their prediction of societally perceived risks of *smart pesticides* and more certain regarding the societally perceived risks of nano-encapsulated food than for the other applications (Table 4.2).

Expert prediction of perceptions of societal need

Seventeen experts (7 from Europe; 5 from India; 2 each from Northern America and Singapore and 1 from Australasia) selected the "no opinion" option for at least one of the five applications, leaving 50 valid responses. A repeated measures ANOVA indicated a significant differences across the five applications, $F(3.27,147.45) = 13.01$; $p < .01$, but no differences attributable to region, $F(4,45) = 2.24$; $p = .07$. There was no significant interaction between expert predictions regarding societal perceptions of need and region, $F(13.10,147.45) = 1.34$; $p = .19$. Pairwise comparison (LSD) between applications showed that *targeted drug delivery* and *water filtration* are predicted to be perceived as societally more necessary, while *nano-encapsulated food* was predicted to be perceived as less necessary (Table 4.2). A repeated measures

ANOVA showed that there is no significant main effect of the application influencing the self-rated certainty of expert's responses, ($F(3.29,148.27) = 1.54$; $p = .19$) and no significant main effect of attributable to region, ($F(4,45) = 0.77$; $p = .54$). There was no interaction effect between self-rated certainty of responses for different applications and region ($F(13.18,148.27) = 1.04$; $p = .41$).

Expert prediction of societal concern about coming into contact with nanomaterials

Nine experts (5 from Europe; 1 each from Northern America, India, Singapore and Australasia) selected the "no opinion" option for at least one of five applications, leaving 58 valid responses. A repeated measures ANOVA indicated significant differences across the five applications, $F(3.71,197.02) = 8.58$; $p < .01$, but no significant differences across regions, $F(4,53) = 0.84$; $p = .50$. No significant interaction effect was found between societal concern and region, $F(14.87,197.02) = 1.54$; $p = .08$. Pairwise comparisons (LSD) between applications showed that, according to experts, societal concern about coming into contact with nanomaterials will be less for applications such as *water filtration*, *food packaging* and *targeted drug delivery*, but more for applications such as *smart pesticides* and *nano-encapsulated foods* (Table 4.2).

A repeated measures ANOVA indicated no significant main effect of application influencing self-rated certainty of expert's responses ($F(3.95,209.43) = 0.50$; $p = .73$) and no significant main effect attributable to region, ($F(4,53) = 0.69$; $p = .60$). There was no significant interaction effect between the certainty of expert's response for different applications across region ($F(15.80,209.43) = 0.89$; $p = .57$).

Expert predictions regarding the importance of societal estimation of the time frame for availability of nanotechnology applications

Twenty-one experts (6 from Europe; 4 each from Northern America, Singapore and India and 3 from Australasia) selected the "no opinion" option, leaving 46 valid responses. A repeated measures ANOVA indicated significant differences across the five applications, F (5.22, 139.11) $= 7.61$; $p < .01$ but no significant difference across the regions, $F(4,41) = 1.59$; $p = .19$. No significant interaction effect was found between timeframe and region, $F(13.57,139.11) = 0.67$; $p = .79$. Based on pairwise comparisons between applications, experts predicted that the public would expect applications such *as water filtration* and *food packaging* to be available before the other applications of nanotechnology (Table 4.2).

A repeated measures ANOVA indicated a significant main effect of application influencing the self-rated certainty of expert's responses, ($F(3.63,149.07) = 5.26$; $p < .01$). However there was no significant main effect attributable to region ($F(4,41) = 2.29$; $p = .07$) nor was there an interaction effect between the certainty of expert's response for different applications across regions ($F(14.54,149.07) = 1.17$; $p = .29$). Pairwise comparisons (LSD) between applications show that experts were less certain regarding the availability timeframe for *smart pesticides* and *nano-encapsulated food* than other applications (Table 4.2).

Importance of factors

Sixty-six experts completed the questions on the importance of the 5 factors regarding societal acceptance of each application (perceived benefit; perceived risk; perceived need; perceived concern about coming in contact with nanomaterials; and time frame for availability) in influencing societal introduction of nanotechnology. One expert from Singapore did not complete this question. A repeated measures ANOVA indicated a significant differences on importance of the five factors, $F(3.07,187.35) = 12.07$; $p < .01$ and no differences attributable to the region $F(4,61) = 1.18$; $p = .32$. Pairwise comparisons between factors showed that experts strongly agreed that perceived risks on the part of citizens will be an important influence the societal introduction of nanotechnology followed by their perceived benefits and their concerns about contact with the nanomaterials. Less agreement was found regarding perceptions of need compared to other factors. Experts neither agreed nor disagreed on the importance of timeframe for the societal introduction of nanotechnology.

There was significant interaction effect between factor and region, $F(12.28,187.35) = 2.04$; $p < .05$ (Table 4.4). Based on pairwise comparisons between factors and countries, no significant differences were found for perceptions of benefit and need. Experts from India were found to agree less than all other experts on the importance of risk perception regarding societal introduction of nanotechnology. In comparison to experts from Northern America, Europe and Australasia, Indian experts were found to agree less on the importance of concerns about coming in contact with the nanomaterials. Experts from India agree more than experts from Australasia on the importance of availability time frame.

Table 4.4. International comparison of the importance of 5 factors on societal introduction of nanotechnology: Estimated marginal mean scores (Standard errors) based on pairwise comparison of simple effect

	Europe[1]	**N. America**[1]	**Australasia**[1]	**India**[1]	**Singapore**[1]
Benefit perception [2]	1.57 (0.23)[a]	2.08 (0.30)[a]	1.82 (0.31)[a]	2.0 (0.30)[a]	1.70 (0.33) [a]
Risk perception [2]	1.52 (0.19)[a]	1.5 (0.26)[a]	1.27 (0.27)[a]	2.67 (0.26) [b]	1.40 (0.28) [a]
Necessity perception [2]	1.91 (0.24)[a]	2.25 (0.32)[a]	2.09 (0.33)[a]	2.17 (0.32)[a]	1.70 (0.35) [a]
Concern about coming into contact with nanomaterials [2]	1.71 (0.20)[a]	1.83 (0.26)[a]	1.55 (0.27)[a]	2.58 (0.26) [b]	1.90 (0.29) [ab]
Timeframe for availability of nanotech applications [2]	2.62 (0.24) [ab]	2.83 (0.32) [ab]	3.18 (0.33)[a]	2.08 (0.32) [b]	2.90 (0.35) [ab]

1 Means associated with the same superscript character are not significantly different between countries. Analysis is based on estimated marginal means using pairwise comparisons (LSD) to compare simple effect between factors and countries ($\alpha = 0.05$)

2 High score is less agreement on the importance of the factor for societal introduction of nanotechnology

4.4 Discussion & Conclusion

The research presented here provides evidence that the 5 factors identified in chapter 3 (Gupta et al., 2012b) are relevant outside of the European regulatory and cultural environment, at least in those regions included in the research. This is relevant to understanding how expert anticipate societal responses to different applications of nanotechnology. The experts indicated that they expect societal responses to vary between different applications of nanotechnology. Societal responses are also expected to be shaped by associated perception of risks, benefits and need, consumer concerns about coming in contact with nanomaterials, and the timeframe for commercialisation. According to experts, *targeted drug delivery* and *water filtration* will be perceived by society as most beneficial and necessary, and applications such as *nano-encapsulated food* and *smart pesticides* will be perceived as least beneficial, unnecessary and riskiest of the 5 applications of nanotechnology included in the survey. Within the context of food-related applications, experts predict a more favourable public response towards *food packaging* than *nano-encapsulated food*. Concerns about coming into contact with nanomaterials will be the greatest for *nano-encapsulated food* and *smart pesticides* and least for *water filtration*, *food packaging* and *targeted drug delivery*, and that people would expect *water filtration* and *food packaging* to be commercialised sooner than most other applications.

Expert views and opinions are not static, and local differences in expert opinion may emerge if consumer views evolve differently in different countries (for example, post-commercialisation of products). It should be emphasised that expert views regarding potential societal responses to novel technologies will inform the development and commercialisation of nanotechnology products (and communication about these). One might anticipate that the first commercialised products will be those which experts perceive will be viewed as most beneficial, (such as water filtration and medical applications of nanotechnology). These applications have typically been framed by experts as less risky than those involving nanotechnology applied to food (te Kulve et al., 2013). If expert assessment of societal responses are inaccurate (as has been the case with other emerging technologies such as GM food), this might result in an inappropriate commercialisation strategy, or produce societal distrust in expert opinions regarding the introduction of new technologies. Comparison between expert and public opinion is therefore needed in order to determine whether what is technically possible from implementation enabling technologies such as nanotechnology aligns with societal preferences. Societally less acceptable applications such as nanoencapsulated food and smart pesticides may be introduced later (once a positive societal response to the more acceptable applications has been established) or even abandoned as application which will be rejected by society, or which may "contaminate" societal acceptance of those applications which have hitherto been accepted.

The current study furthermore shows that the factors influencing societal introduction of nanotechnology differ in terms of their importance by the experts. Risk perception emerged as the most important factor influencing societal introduction of nanotechnology, followed by benefit perception and concerns about contact with the nanomaterials. While experts did not indicate risks as important factor in shaping public acceptance of nanotechnology in previous study (chapter 3: Gupta et al., 2012b), they indicated it as the most important issue when explicitly confronted with the issue of risk perception. This difference may be attributable to the different methodologies adopted in these studies. Alternatively experts may need to be reminded of the importance of societal risk perceptions to ensure appropriate risk mitigation strategies in line with societal priorities are in place. Less agreement was found between experts regarding the importance of perceived need and timeframe for the availability of nano-products.

An interesting issue relates to the extent that experts were certain that their responses were accurate. Experts were more certain that the public will perceive nanoencapsulated food as a risky application of nanotechnology compared to the other applications. Although no reasons are given, a speculative interpretation is that that the unavoidable consumption of nanoparticles may contribute to this effect. Future research should, however, aim to address this issue. Against this, experts are less certain as to how risky or beneficial smart pesticides will be perceived to be by the public. The uncertainty regarding smart pesticides may be rooted in the historical debate associated with pesticides (Carson, 1962; Gunter and Harris, 1998; Kinkela, 2005). On one hand, pesticide use is seen to lead to increased productivity benefitting farmers, processors, and consumers, while on the other their use may lead to environmental and health problems (Zilberman et al., 1991). Experts may be uncertain as to which way society will react given these past controversies.

In terms of importance of the 5 factors investigated in this study, it is of interest to note that experts from India were found to differ in their opinion compared to other international experts. Specifically, they felt that timeframe for market availability of nano-products will be a more important factor influencing societal introduction of nanotechnology, and that perceived risk and concerns about contact with the nanomaterials will be less important in determining societal acceptance. India represents the only developing country in the research, where local societal problems are potentially greater and arguments for technological solutions to these problems more convincing, resulting in perceived risk being of relatively lower importance than perceived benefits. Alternatively, less societal discussion of the risks of technological innovation may have reduced local expert prioritisation of the importance of societal acceptance. Nanotechnology development in India is at a nascent stage and is largely a government led initiative. For example, nanotechnology is promoted widely as a technological solution to enhance food security, which is a more pressing problem in the developing world (Sastry et al., 2011). Whether the findings of the present study can be generalised to all BRIC countries, or if they are specific to the Indian case warrants further research.

There is currently very little regulation that relates specifically to nanotechnology in any field of application, including in relation to food. Bowman and Hodge (2007) have observed that, internationally, despite the extensive scientific and commercial interest linked to nanotechnology, there has been only limited debate on the associated regulatory and legal aspects. Regulators therefore rely instead on a range of other relevant current regulation designed principally with applications other than nanotechnology in mind. For example, even in the area of application to food production, the relevant European regulations that need to be considered extends from REACH, (the EC Regulation No. 1907/2006 on Chemicals, aimed at preventing harm to humans or the environment), through the Waste Framework Directive 2008/98/EC to the Novel Foods Regulation (EC) No. 258/97) (Coles and Frewer, submitted). International harmonisation of regulations would simplify international trade. The results suggest that experts indicate that they expect different levels of societal acceptability of different applications. According to experts, this implies that different standards for different areas of application (for example, in relation to food related applications) may be needed to generate societal trust in consumer and environmental protection legislation associated with nanotechnology. It is important to note that consumer priorities and preferences for legislative practice also need to be taken into account, as these do not necessarily align with expert expectations of what these might be.

Generally, expert views regarding societal responses to different applications of nanotechnology were homogenous, independent of local variations in regulation or consumer acceptance of novel technologies and their applications. Experts from Europe and Australasia tended to emphasise perceived societal risk more for certain applications, whereas experts from India, Northern America and Singapore emphasised the importance of benefit perception. Experts also indicated that agri-food applications of nanotechnology would be more acceptable in Northern America, Singapore and India and less so in Europe and Australasia. This may reflect differences in the regional history of regulation, adoption and exploitation of GM agriculture and food production. Europe and Australasia has emphasised risk and Northern America, and countries with more technological dependence such as India and Singapore have emphasised benefits and need. Nevertheless the similarities in expert opinions between geographical locations were more pronounced than the differences. This implies that the expert communities sampled are in agreement regarding the societal acceptability of food-related nanotechnology applications. If such expert views are predictive of emergent policy associated with the introduction of nanotechnology food products, regulatory harmonisation may be less difficult than has been the case for GM. However, regional and national differences in regulatory infrastructure and differences in consumer acceptance will also influence regional and national policy. However, it is not possible to claim that this finding is definitive and, as such, can be applied globally. Further research is required to compare expert views from non-English speaking countries to provide a more comprehensive view of international expert opinion regarding potential societal responses to nanotechnology. In addition, food experts were somewhat overrepresented in the current sample. This may be because of the larger sensitivity to social research by food scientists after GM, or be a reflection of the professional network of the researchers in this study.

Nevertheless, within the region specific confounds from the present study it can be concluded that perceived risk and benefit and contact with nano-particles are universally considered by experts as most important factors influencing societal acceptance of nanotechnology.

CHAPTER 5

Public Perceptions of Different Applications of Nanotechnology: A UK Study

Abstract

Examining perceptual factors people use to form attitudes and opinions about emerging technologies such as nanotechnology can be useful for both industry and policy makers involved in development, implementation and regulation of nanotechnology. A broad range of different socio-psychological and affective factors may influence public responses to different applications of nanotechnology. A useful approach to identifying relevant public concerns and innovation priorities is to develop predictive constructs which can be used to differentiate applications of nanotechnology in a way which is meaningful to consumers. This requires elicitation of constructs from consumers rather than measuring those assumed to be important by the researcher. Psychological factors influencing societal response to 15 applications of nanotechnology drawn from different application areas (e.g. medicine, agriculture and environment, food, military, sports, and cosmetics) were identified in this way using Repertory grid method in conjunction with generalised Procrustes analysis. The results suggested that people differentiate nanotechnology applications based on the extent to which they perceive them beneficial, useful, necessary and important. The benefits can be offset by perceived risks focusing on fear, ethical concerns, and perceived equity regarding who will gain the benefits of nanotechnology products. Compared to an earlier expert study on societal acceptance of nanotechnology, consumers emphasized fair distribution of benefits compared to experts, but had less concern regarding potential physical contact with the product and time to market introduction. Also consumers envisaged fewer issues with several applications compared to experts, in particular food applications. This confirms the importance of eliciting concerns from the public.

5.1 Introduction

Public opinion regarding the applications and development of nanotechnology is likely to be a key determinant influencing its future development and implementation trajectory (Royal Society and the Royal Academy of Engineering, 2004). Indeed, the potential economic and social benefits of nanotechnology may not be realized if societal acceptance issues are not adequately addressed early in the development process (Macoubrie, 2006; Renn and Roco, 2006). Public opinion should be given due consideration while formulating regulations and policies related to nanotechnology (Kyle and Dodds, 2009; Powell and Colin, 2008), as well as the design of specific applications and products (Frewer et al., 2011c). It has been long established that societal responses to emerging technologies result from a diverse range of considerations, many of which are not technical in origin (Saba and Frewer, 1998; Jasanoff, 1993), and, as outlined in Chapter 2, a broad range of different socio-psychological and affective factors may potentially influence public acceptance of nanotechnology (Gupta et al., 2012a). Risk and (more recently) benefit perceptions and associated attitudes have been the focus of most of the social science literature on public acceptance of new technologies (Alhakami and Slovic, 1994; Gaskell et al., 2004a; Poortinga and Pidgeon, 2006; Purvis-Roberts et al., 2007; Schulte et al., 2004; Sjoberg and Drottz-Sjoberg, 2001; Slovic, 1996; Slovic et al., 1991). In particular, the analyses of an individual's response to potential risks, including affective responses, has been used to explain why discrepancies between expert and lay assessments of the risks associated with different potential hazards has occurred (Fischhoff et al., 1978, 1984; Slovic, 1987). Research on risk perception has demonstrated the importance of the "affect heuristic" (Finucane et al., 2000; Fischer and De Vries, 2008; Slovic et al., 2007, 2002) and intuitions (Loewenstein et al., 2001) in guiding risk perceptions and risk-related behavior. Modern theories in cognitive psychology and neuroscience have suggested that two fundamental ways are used by laypeople to analyze risk; the "analytical" or "rational" system and the "experiential" system. The rational system is driven by rules of logic and evidence while experiential system translates reality in images, narratives and metaphors which are associated with affective feelings. Both operate in parallel when an individual is making decisions about a potential hazard (Slovic et al., 2004).

Previous research on risk perception of new technologies has also indicated that scientifically trained experts tend to perceive risk differently than the public. Scientific experts are shown to consider more technical and quantitative factors such as morbidity, mortality and probability of occurrence of a hazardous event, while lay people takes account of qualitative risk characteristics such as dread, fairness, freedom to take or avoid risk while forming opinion about risks, including those related to new technologies (Barke and Jenkins-Smith, 1993; Blok et al., 2008; Sjoberg, 1999; Webster et al., 2010). One of the challenges of risk communication is to address both expert's and public's perceptions of risks (Sandman, 1987). Understanding how lay and expert view align, or misalign will influence not only the development of effective communication about nanotechnology (and other controversial technologies), but can also be used to inform the final design of specific applications, and their order of entry into the market place (Frewer et al., 2013b). At present, the general public appears to know or understand little about nanotechnology (Farshchi et al., 2011; Pidgeon et al., 2009; Priest, 2006; Ronteltap et al., 2011; Satterfield et al., 2009; Sheetz et al., 2005; Siegrist et al., 2008a; Vandermoere et al., 2010). However, people are still able to make decisions or judgments about the acceptability of nanotechnology and /or its applications (Scheufele and Lewenstein, 2005).

Past research into public perceptions of nanotechnology has suggested that risk *benefit* perception represents important determinant of nanotechnology acceptance (Burri, 2007; Conti et al., 2011; Retzbach et al., 2011; Smiley Smith et al., 2008). The majority of studies on public perception of nanotechnology have shown that overall public opinion on nanotechnology is somewhat positive, and the perceived benefits of nanotechnology may outweigh the perceived risks (Bainbridge, 2002; Burri and Bellucci, 2008; Cobb and Macoubrie, 2004; Priest and Greenhalgh, 2011; Satterfield et al., 2009; Scheufele and Lewenstein, 2005; Stampfli et al., 2010). More in depth understanding on the different dimensions on which risk and benefits are weighed is however lacking for consumers.

Public perceptions of nanotechnology are not created in a complete vacuum, even in the absence of public knowledge. The media has been found to be influential in engaging and influencing public opinion on nanotechnology (Donk et al., 2012; Groboljsek and Mali, 2012; Ho et al., 2011; Petersen et al., 2008; Scheufele and Lewenstein, 2005; Schütz and Wiedemann, 2008). The importance of information provided by the media may allow the use of cognitive shortcuts or heuristics and trust in scientists in shaping public opinion about nanotechnology (Scheufele and Lewenstein, 2005; Smiley Smith et al., 2008). Other studies indicate that public views on science and technology in general may be an important predictor of peoples support for nanotechnology (Retzbach et al., 2011; Scheufele and Lewenstein, 2005; Vandermoere et al., 2011). General attitudes toward technologies that have been already introduced may also influence the perceived benefits associated with different applications of nanotechnology (Stampfli et al., 2010), as do religious beliefs (Brossard et al., 2009; Scheufele et al., 2009). Trust in industry (Siegrist et al., 2007a)and/or government (Macoubrie, 2006) has also been found to influence nanotechnology acceptance, such that the higher the levels of social trust placed in industry or government, the more likely it will be that the public will accept the application of nanotechnology. Social justice and vulnerability are also found to influence risk perceptions of nanotechnology (Conti et al., 2011). A good description of consumer perceptions of nanotechnology should be sensitive to pick up these, and other potentially unidentified, influences.

The perceived characteristics of different types of nanotechnology application may also influence acceptance for example, Priest and Greenhalgh (2011) reported that most future benefits anticipated by participants in their study were in the areas of medical advances. Conti et al. (2011) studied variation in risk perception between energy, food and medical applications of nanotechnology and showed that nano-enabled food is most likely to raise societal concern than other applications. Perceived "bodily invasiveness" was also influential in determining acceptance, with most consumer negativity reserved for food-related applications. Despite the potential importance of specific features of technological innovation to societal acceptance, however, the majority of studies on public perception of nanotechnology have focused on general applications, rather than looking at specific applications (Cobb and Macoubrie, 2004; Gaskell et al., 2004b; Lee et al., 2005; Scheufele and Lewenstein, 2005; Sheetz et al., 2005). Previous research has tended to utilize survey methodologies where questions identified as relevant by the researcher were included, or where questions were derived from existing theoretical models of technology acceptance. Such an approach may fail to capture the broad range of factors influencing societal response to nanotechnology if these were not considered as important when the study was designed (Saba and Frewer, 1998; Frewer et al., 2011a). Furthermore, research regarding public perceptions associated with the introduction of emerging technologies needs to focus specifically on the technology under consideration, as extrapolating from public responses to other technologies previously introduced may not necessarily be appropriate (Frewer et al., 2011a). An important element in identifying citizen concerns and innovation priorities is to allow them to express these in their own words, and develop predictive "constructs" which can be used to differentiate different applications of nanotechnology in a way which is meaningful to consumers (Cormick, 2009; Currall et al., 2006; Gupta et al., 2012b; Pidgeon et al., 2009; Siegrist et al., 2007a).

A methodological approach that is well suited to address such a research question is the repertory grid methodology (Kelly, 1955) in conjunction with generalised Procrustes analysis (GPA) (Gower, 1975). The repertory grid method (RGM) originated in psychology, and has been used in number of studies across different disciplines to elicit individual's perception on new technologies and or products

(Frewer et al., 1997, 1998a; Gupta et al., 2012b; Lewith and Chan, 2002; Messina et al., 2008; Mireaux et al., 2007; Rowe et al., 2005; Russell and Cox, 2004; Tio et al., 2007).The repertory grid method allows respondents to determine personal constructs of importance in their own words without imposing external, researcher bias or vocabulary (Mireaux et al., 2007; Schaffalitzky et al., 2009). The method is efficient in identifying the full range of constructs that people use for evaluating an issue in a particular context (van de Kerkhof et al., 2009). The data from repertory grid method can be analyzed using generalised Procrustes analysis that allows the identification of constructs about which respondents agree, so that the most important determinants can be identified. GPA is a multivariate statistical technique that aims to identify consensus between respondent assessment patterns and provide a measure of respondent agreement with as little intervention on the part of the researcher as possible (Wemelsfelder et al., 2000). It is particularly useful when information is required about how individuals differ and to what extent they agree in their perception of the same topic (in this case, specific applications of nanotechnology)(Dijksterhuis and Gower, 1991). By analyzing the results using GPA, variations due to respondents using different terms to describe the same stimuli and / or variation in their use of rating scales can be controlled for (Mireaux et al., 2007).

Thus the aim of the current study was to determine the psychological constructs that shape public perception of nanotechnology. This was achieved through applying repertory grid methodology to identify factors influencing participants responses to different applications of nanotechnology combined with GPA analysis.

5.2 Methods

Participants

Structured interviews were carried out with eighteen participants, 10 men and 8 women (mean age $= 40.6$ years, $SD = \pm 14.5$ years), recruited from Newcastle Upon Tyne in the UK by a social research company, and selected from a range of ages and socioeconomic groups. Although a sample of this size cannot be said to be nationally representative, the respondents represented a good cross section of UK age and socioeconomic groupings.

Design

Applying the repertory grid method, respondents were asked about 15 applications of nanotechnology drawn from different areas (e.g. medicine, agriculture and environment, chemical, food, military, sports, and cosmetics). For both nanotechnology in general and the 15 applications, a brief explanation was provided (Table 5.1). The survey used 10 triads (each triad consisted of set of 3 applications) compiled from the 15 specific applications of nanotechnology to initiate construct elicitation. Triads were presented in randomized order with each application being presented twice (in different triads) to each respondent. For each triad, respondents were asked, "which 2 out of these applications of nanotechnology do you find to be similar in terms of societal response, and why?" and "which of these applications of nanotechnology is different from the other 2 applications in terms of societal response, and why?" to create bipolar arguments on differences between the applications. Once all 10 triads had been used to elicit arguments, respondents evaluated each application of nanotechnology, against each bipolar construct developed from their repertory grid interview on a 5-point scale, with one pole of the construct at score 1 and the other pole at score 5.

Procedure and data collection

The data were collected in a face-to-face interview. All respondents were given a short description of nanotechnology at the outset of the experiment. The interview was divided into 2 phases. In the first phase, constructs describing determinants of societal response to nanotechnology were elicited. This was followed up during the second phase where the respondents rated each of the applications on each construct they had personally described as relevant. The interviews were conducted between March 13–23, 2012 using Idiogrid software (Grice, 2002). All interviews were audio- taped after receiving verbal consent from the interviewee. On average it took 55 minutes to complete the interview.

Table 5.1. Specific applications used in the generation of constructs about nanotechnology

Nanotechnology: uses very small particles (less than a billionth of a metre in size) to deliver new applications of products and services (for example in medicine, cosmetics, engineering and food products)
Targeted drug delivery (release of medications): capsules using nanomaterials can be made that will allow the release of medications specifically in the target organ. The risk of side effects can thus be reduced.
Brain implants: often referred as neural-implants are technological devices that connect directly to a brain. Nanomaterials can be used to develop robust neural implants that can be used to simulate brain circuit activity. **Easy to clean surfaces:** Nanomaterials can be used to manufacture, dirt and water-repellent surfaces for e.g. self-cleaning windows.
RFID tags: with use of nanotechnology, high-volume manufacture of very inexpensive RFID tags can be done. These inexpensive, printable transmitters can be invisibly embedded in packaging. It would allow a customer to walk a cart full of groceries or other goods past a scanner on the way to the car; the scanner would read all items in the cart at once, total them up and charge the customer's account while adjusting the store's inventory.
Encapsulation and delivery of nutrients in food: Nanoparticles encapsulate the vitamins or other nutrients and carry them through the stomach into the bloodstream. For many vitamins this delivery method also allows a higher percentage of the nutrients to be used by the body because, when not encapsulated by the nanoparticles, some nutrients would be lost in the stomach
Food packaging: With nanoparticles, synthetic packaging that kill germs can be produced. Meat, for example, can thus be preserved for a longer period of time.
Smart pesticides: developed using nanotechnology to enhance the effectiveness or delivery of pesticides. **Chemical sensors:** designed using nanomaterials to detect very small amounts of chemical vapors, given off by explosives and drugs.
Fuel cells: Nanotechnology makes it possible to store a large amount of hydrogen (a gasoline substitute) in a very confined space that can be used in automobiles.

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Table 5.1. Specific applications used in the generation of constructs about nanotechnology

Environment Remediation (clean up): Nanoparticles can be used to clean contaminated water, soil or air, as their small size allows them to absorb the contaminants more efficiently and the method is less expensive as compared to other filtration methods.
Water filtration: Together with light, certain nanoparticles can destroy bacteria and toxins in water.
Smart-dust used for military intelligence: Smart dust refers to tiny, wireless networks of sensors. You also could think of the sensors as tiny chips, or even miniature robots. The smart dust detects data about light, temperatures or vibrations and transmits that data to larger computer systems
Cosmetics: containing nanoparticles used to enhance active ingredient absorption (e.g. sunscreens; anti-ageing creams); Sunscreens with nanoparticles is transparent and has a high level of cutaneous tolerance.
Nanofabrication/Clothing: Textiles with nanoparticle surface coating are highly soil-resistant and water repellent. Food stains can thus be removed completely with water. Also crease free shirts and stink free socks can be manufactured using nanomaterials.
Sports goods: Nanomaterials can be used to increase the strength of the tennis racquets which increases control and power when you hit the ball. Nanomaterials can also be used to reduce the amount of air leakage from tennis balls so they keep their bounce longer.

Analysis

The aggregated data from the 18 participants consisted of 360 constructs in total. The number of constructs elicited from each participant ranged from 19 to 20, with the mean number of constructs being 19.6. The constructs were classified into series of construct–classes. Subsequently, a different researcher applied the initially defined construct–classes to the constructs. A Cohen's kappa of 0.74 indicated good agreement between the coders regarding the classification of the constructs. Differences were then resolved by further discussion to achieve consensus on classification and in total 60 construct–classes were finalized (Appendix A.3). The construct–classes were based on abstractions of the actual constructs; for example, if a respondent stated that he or she found the applications "useful for particular section of society", this was deemed to fall within the class of "useful for subgroup of people". Some constructs were classified as combination of two construct–classes for e.g. “health benefits + environment benefits”.

The grid data for each respondent derived from repertory grid interviews was submitted to GPA using Idiogrid software. A GPA group average perceptual space was obtained, illustrating the relative positions of the 15 applications of nanotechnology. GPA allows each respondent to have unique set of attributes by transforming the resulting data by translation, rotation or reflection in order to find consensus among the respondents. The consensus proportion obtained using GPA, represents the average of all the transformed configurations. Interpretation of this consensus helps in the identification of the most salient constructs. To interpret the dimensions of the profile spaces derived from GPA, Principle Component Analysis (PCA) is performed using Promax rotation, on the consensus grid obtained from GPA (Grice and Assad, 2009). To identify the most salient psychological constructs, the structure loadings for each construct was examined on the principle axis. To select the principle construct classes, a pragmatic approach have been adopted, where only those construct–classes occurring 3 or more times with loading coefficients ($\leq$ -0.50 or $\geq$ 0.50) were considered to be important. These were further used for labeling the principle component on which it loaded (bold, Table 5.2). Once the most salient constructs were identified using PCA, the transcribed interviews were reviewed to identify statements that supported public views about the constructs, explaining differences associated with the different applications of nanotechnology.

Table 5.2. Total number of occurrences of construct class with high loading coefficients (≤ -0.5 or ≥ 0.5) on the first three principal axes

Construct Class	**PC 1**		**PC 2**		**PC 3**	
	(+)	(-)	(+)	(-)	(+)	(-)
Alternatives are available	0	0	0	1	0	**3**
Beneficial for more people	**3**	0	1	0	**4**	0
Benefits for a subgroup of people in society	0	**3.5**	0	1	0	1.5
General benefits	**7**	0	2.5	0	**3**	0
Could be misused/abused	0	**3**	0	0	0	0
Daily use	**6**	0	1	0	0	0.5
Desired by everyone	**6**	0	**3**	0	0	1
Doubts	2	**3.5**	2	2.5	1	**3**

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Table 5.2. Total number of occurrences of construct class with high loading coefficients (≤ -0.5 or ≥ 0.5) on the first three principal axes

Construct Class	PC 1		PC 2		PC 3	
	(+)	(-)	(+)	(-)	(+)	(-)
Environmental benefits	**7**	0	1.5	**4**	**4**	1
Fear	0	**3.5**	0	0	0	0
Health benefits	**7.5**	0	**20**	0	**14.5**	0
Important	0	0	1	0.5	**3**	0.5
Generally fewer or no benefits	0	**7.5**	0	**6**	0	2.5
Less/not desirable	0	**3.5**	0	**3**	0	1
Less/not necessary	0	1.5	0	**8**	0	**12**
Less/not important	0	1	0	**4**	0	**7**
Makes lifestyle easy	**3**	0	0	0.5	0	1.5
Necessary	**3**	0	**8**	0	**14.5**	0
Nice to have but not essential	0	0	0	2	0	**7**
No personal knowledge	0	**5**	0	2	1	0
Not acceptable to society	0	**4**	0	2	0	0
Personal benefits	1	0	**3**	0	1	**3**
Privacy concern	0	**4**	0	1	0	2
Useful for general public	**8**	0	**4**	1	2	1
Useful for subgroup of people	0	**16**	0	**7**	**3**	2

* Following (Gupta et al., 2012b), construct–classes coded as a combination of two different construct–classes was added as 0.5 to each of the classes separately allowing for decimals in the frequency count.

5.3 Results & Interpretation

The consensus proportion was found to be 0.62 indicating that the GPA consensus grid represented participant views about the 15 applications with respect to their self-generated constructs reasonably well. The consensus proportion was tested for statistical significance using a randomization test (Wakeling et al., 1992). Simulations of 1000 trials were generated based on the current data and showed that the observed consensus proportion were not the result of a random dataset (significant at $p < .001$). The consensus proportion for the two most extreme respondents was found to be 0.25 and 0.67 respectively indicating that there was relatively little variance in response with respect to the consensus grid. Consensus ratio's for applications of nanotechnology ranged from 0.33 to 0.75 (Table 5.3).

Higher consensus was found for applications such as easy to clean surfaces, smart dust, environment remediation, sports goods, water filtration and medical applications of nanotechnology. More variation between participant opinions was found for applications such as nano-fabrics, encapsulation of nutrients in food, food packaging, chemical sensors, fuel cells and cosmetics.

Table 5.3. Consensus proportion for applications of nanotechnology from lowest to highest consensus proportion

Application	**Consensus/Total**
Fuel cells	0.33
Cosmetics	0.39
Chemical sensors	0.53
Food packaging	0.53
Encapsulation and delivery of nutrients in food	0.6
Nano fabric	0.6
Brain implants	0.61
Smart pesticides	0.63
RFID tags	0.64
Sports goods	0.65
Easy to clean surfaces	0.66
Targeted drug delivery	0.67
Water filtration	0.69
Environment Remediation (clean up)	0.69
Smart dust for military use	0.75

Interpretation of the results was limited to first three principal components (PC), based on the criterion Eigen values > 1 (with the first four Eigen values being 4.16, 2.21, 1.07 and 0.75). The three components together accounted for 74.3% of the variance. Table 5.2 lists the number of construct–classes that have high correlations with the first three PC. Only those construct–classes that occur 3 or more times are considered important. A number of construct–classes were identified that loaded on more than one principal component. This can be interpreted by taking into account the correlation between the components.

That is, if two components are correlated then an association between a construct–classes and one of these two components implies a correlation between the construct–classes and the other component. Moderate correlation (Cohen, 1992) was found between PC1 and PC2 (0.35) and between PC2 and PC3 (0.32). Low correlation (Cohen, 1992) of 0.05 was found between PC1 and PC3.

The first principle component (PC1) explains 41.6% of the data variation. The constructs used to describe determinants of public response to different applications of nanotechnology on the positive end of PC1 are "beneficial for more people", "general benefits", "daily use", "desired by everyone", "environmental benefits", "health benefits", "makes lifestyle easy", "necessary", and "useful for general public". The positive end of PC1 was labeled as "**general benefits to society"**. The negative pole of PC1 was described by the constructs "could be misused\abused", "doubts", "fear", "generally fewer or no benefits", "no knowledge", "not acceptable to society", "less\not desirable", "privacy concern", and "useful for subgroup of people" (Figure 5.1), reflecting negative attitudes. This component was therefore labeled as "**fear, risk, ethical concern and uncertainty regarding who benefits**". Constructs such as "daily use", "makes lifestyle easy", "could be misused\abused", "fear", "no personal knowledge", "not acceptable to society, and "privacy concern" were found to only load on PC1. PC2 explains 22.1% of the data variation. The positive pole of PC2 relates to constructs such as "desired by everyone", "health benefits", "necessary", "personal benefits", and "useful for general public". Therefore this pole of PC2 can be described as "**personal benefits and need**". Constructs found on the negative pole of PC2 are "environmental benefits", "generally fewer or no benefits", "less\not necessary", "less\not important", "less\not desirable", and "useful for subgroup of people" and can be characterized as "**lack of need**" (Figure 5.1). The third Principle component (PC3) explains 10.6% of variance. It has its positive pole associated with "beneficial for more people", "general benefits", "environmental benefits", "health benefits", "important", "necessary", and "useful for subgroup of people". This pole of PC3 can be labeled as "**important** and/or **necessary**". Constructs highlighted on the negative end of PC3 are "alternatives are available", "doubts", "less\not necessary", "less\not important", "nice to have", "personal benefits" and therefore the negative side of PC3 can be defined as "**only one of many alternatives available** " (Figure 5.2). Constructs found to only load on PC3 are "important", "alternatives are available", and "nice to have but not essential". Note that as a consequence of the promax rotation allowing for correlation between the principle components, the explained variances of the three components do not add up to the overall explained variance.

On the basis of the constructs associated with each principal component, it is possible to make some inferences about how respondents have characterized the 15 applications of nanotechnology. Along PC1 (Figure 5.1), which is primarily associated with general benefits to society at one pole along a continuum with risk, fear, ethical concerns and uncertainty regarding who benefits associated with the other, applications such as *water filtration, easy to clean surfaces, nanofabrics, encapsulation and delivery of nutrients in food, food packaging, targeted drug delivery* and *environmental remediation* are positioned positively, indicating these applications to be associated with general benefits to the society and health and environment benefits:

> "*Water filtration will lead to massive humanitarian benefits to society*" (Respondent 16)
>
> "*Most people will be happy to receive nanomedicine*" (Respondent 2)
>
> "*Nanofabrics may lead to use of less detergent hence an environment friendly product*" (Respondent 11)
>
> "*Environmental remediation is completely beneficial as it leads to sustainability*" (Respondent 13)

Applications such as *RFID tags, chemical sensors, brain implants, sports goods, smart pesticides* and *smart dust for military use* were rated less positively on this continuum, indicating these applications to be rated by respondents as being risky, invoking fear, raising ethical concern and also there is uncertainty of who would benefit from using these applications:

> "*RFID could put people out of jobs*" (Respondent 1 and 14)
>
> "*Nano pesticide need to be tested fully to confirm that there is no leakage from one field to another*" (Respondent 2)
>
> "*I would be very uneasy with brain implants as brains are very complicated, same with smart dust, doubts on what kind of information others might collect*" (Respondent 8)

"*RFID tags would be invasive, and people are always defensive about such applications*" (Respondent 16)

Cosmetics and *fuel cells* were rated as neutral along this continuum. Of all the applications, *smart dust* was seen as most risky, while *water filtration* was seen as the most beneficial application of nanotechnology to the society.

PC2 (Figure 5.1), differentiates different applications on the basis of how necessary they are perceived to be. *Targeted drug delivery, brain implants, water filtration, encapsulation and delivery of nutrients in food, food packaging, environmental remediation* and *cosmetics* are positioned on the positive side of this continuum, indicating that they are associated with personal benefits and are deemed more necessary, for example:

"*Brain implants and water filtration could be necessary for a lot of people*" (Respondent 10)

"*Nanofood, I would buy it personally, as it will be a positive effect to have added nutrients in your food*" (Respondent 10)

"*Cosmetics would give more personal benefits*" (Respondent 17)

On the negative side of PC2 are applications such as *nanofabrics, chemical sensors, fuel cells, sports goods, RFID tags, easy to clean surfaces, smart pesticides* and *smart dust for military use*. Lack of need was seen to be associated with these applications of nanotechnology:

"*Easy to clean surfaces is nice to have but not really necessary*" (Respondent 10)

"*Smart pesticides are not necessary*" (Respondent 12)

PC3 (Figure 5.2) corresponds to the distinction between applications that are considered important and or necessary to applications that are considered to be only one of the many alternatives available to the public. Applications located on the positive side of PC3 are *water filtration*, *environmental remediation*, *targeted drug delivery, brain implants, chemical sensors, fuel cells* and *smart pesticides*.

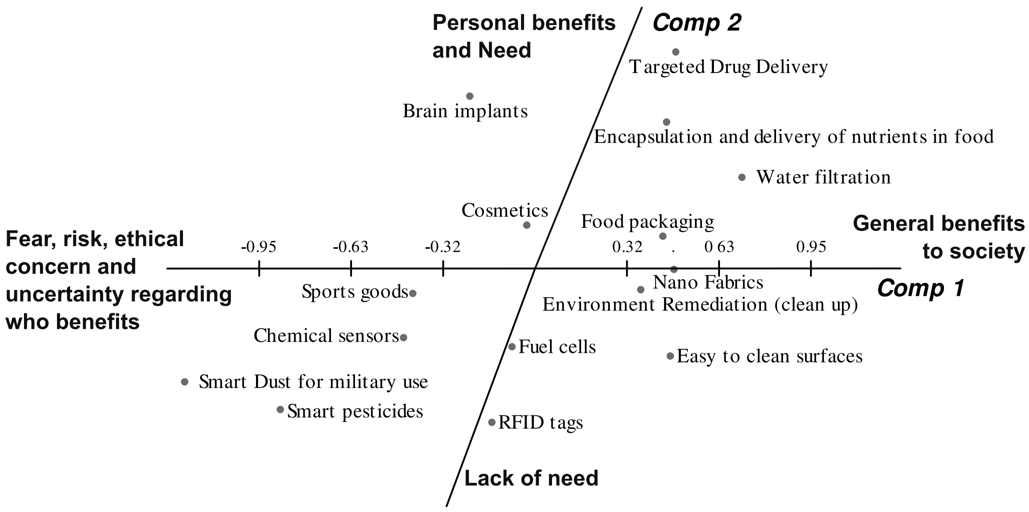

Figure 5.1. Location of applications of nanotechnology on first and second principal component.

These applications are considered as being more important and/or necessary:

> "*Brain implants are really important... if you have illness*" (Respondent 1)

> "*Medical applications are definitely most important ones*" (Respondent 4, 12)

> "*Water filtration will be very important for the third world countries*" (Respondent 8, 11)

On the negative side of this dimension were applications such as *smart dust for military use, nanofabrics, cosmetics, RFID tags, easy to clean surfaces* and *sports goods*, which are described as only one of many alternatives.

> "*Fabrics you can have alternatives*" (Respondent 9)

> "*Easy to clean surfaces is no added value using nanotechnology, we can do the cleaning ourselves*" (Respondent 12)

Food packaging and *encapsulation and delivery of nutrients in food* were rated as neutral applications on this continuum on PC3.

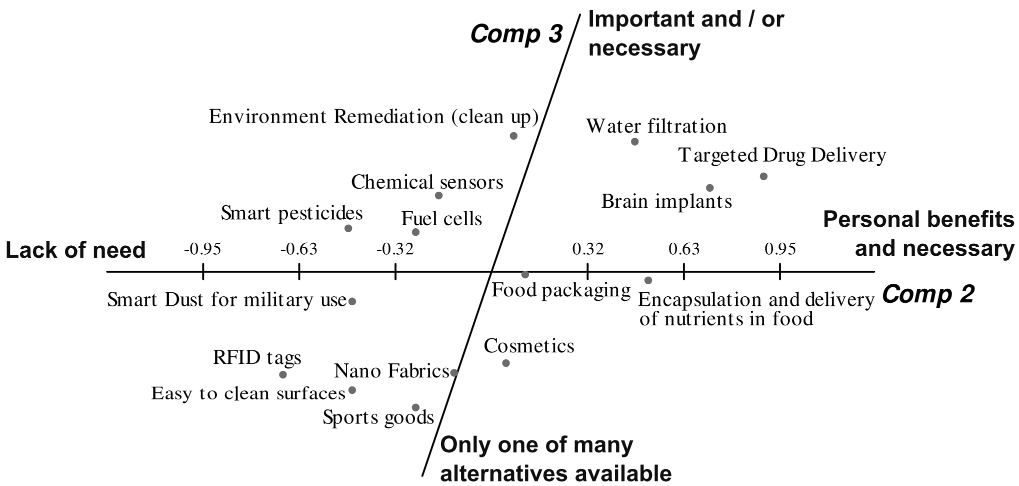

Figure 5.2. Location of applications of nanotechnology on second and third principal component.

5.4 Discussion

Consistent with findings from previous studies (Farshchi et al., 2011; Pidgeon et al., 2009; Ronteltap et al., 2011; Satterfield et al., 2009; Vandermoere et al., 2011), the majority of participants reported being unfamiliar with nanotechnology and its applications. Despite this, participants were able to differentiate between different applications of nanotechnology on the basis of perceived need, benefit, usefulness, and importance. Risks, ethical concerns and the issue of to whom the benefits of different applications would accrue were also considered to be factors potentially influencing acceptance.

The results suggest that people may differentiate different applications of nanotechnology based on their perceptions of associated benefits. These may also vary according to the type of application, For example, health benefits were associated with food and medical applications of nanotechnology, while environmental benefits were linked to fuel cells, environmental remediation, and nanofabrics. In addition, applications were also differentiated on the basis of whether or not they bring benefits to society as a whole or whether these benefits are experienced by individuals. Water filtration was rated as the most beneficial application of nanotechnology. Even though the majority of the participants felt that they would not need this application in the UK, they simultaneously acknowledged that water filtration using nanotechnology will bring benefits to developing countries. Medical and environmental applications were seen as the most beneficial applications, in line with existing research (Conti et al., 2011; Priest and Greenhalgh, 2011). However, food applications were also rated as beneficial for society, in contrast to previous studies (Burri and Bellucci, 2008; Cormick, 2009; Siegrist et al., 2008a; Vandermoere et al., 2011). This may be attributable to methodological differences (other studies have utilized researcher generated constructs to assess perceptions, whereas in the current study, people were asked to rate applications on their self-generated constructs, and risk did not emerge as an important factor). In addition, the current research utilized descriptions of the tangible benefits of the food-related applications. This suggests that the development of products with desirable consumer benefits will increase acceptance, assuming other acceptance criteria such as consumer choice and product traceability are met.

The concepts of need, usefulness and importance also emerged as important constructs. According to participants, the perceived benefits alone would not be the decisive factor in societal acceptance, but other relevant factors, such as the extent to which the application is perceived to be important or necessary, or "trivial", will shape public responses to different applications. Food and medical applications were seen to be the most useful and necessary applications of nanotechnology, while applications such as RFID tags, and smart dust for military use, were viewed as unnecessary. Nanoproducts such as sports goods, cosmetics and nanofabrics were seen applications where different technological approaches would deliver products with the same properties, and so the use of nanotechnology in their production was unwarranted.

The results also suggest that negative public reactions will be driven by perceptions of fear, concerns about privacy, ethical concerns, and low levels of (perceived) knowledge about the different applications of nanotechnology. In this study, applications such as RFID tags that were associated with negative socio-economic impacts (such as unemployment), suggesting that these may be as relevant as health and environmental risk in determining acceptance. Doubt and uncertainty regarding the equity of the distribution of the benefits emerged as an important ethical concern among the participants. For applications such as brain implants, pesticides, smart dust and cosmetics, participants doubted that everyone would have access to the benefits associated with such applications. In addition there were doubts about certain applications whether they would deliver the benefits as promised or would they be oversold in terms of the benefits they will potentially deliver. Participants also expressed that they feared misuse of applications such as smart dust, RFID tags and pesticides. The first two of these applications were also seen to raise privacy concerns.

If comparisons are made with expert assessments of the determinants of the societal acceptance of different applications of nanotechnology (Gupta et al., 2012b), similarities and differences with the lay participants in this sample can be identified. Experts identified the main factors influencing societal response to different applications of nanotechnology being the extent to which applications are perceived to be beneficial, useful, and necessary; similar to the consumers in the current study. Two additional factors were deemed important for public acceptance by experts that were not raised by consumers themselves. These were (1) concern over coming into contact with the nanomaterials used and (2) how close to the market the application is. In the current study, participants also identified one issue that was not identified by experts; which related to ethical concerns, and the issue of equity of distribution of the benefits as potentially influential determinants. Regarding the applications, both experts and lay participants indicated that medical applications and water filtration that are likely to be considered as the most beneficial and necessary applications of nanotechnology in the societal debate. However, experts perceived that food-related applications of nanotechnology (in particular encapsulation and delivery of nutrients in food) will be less acceptable to society. Lay participants perceived food applications of nanotechnology to be beneficial; suggesting that societal acceptance of food-related applications may not be as negative as assumed by the expert community, assuming benefits are tangible and desired by consumers.

While the level of consensus suggests that the identified factors are important indicators for societal responses to nanotechnology, the generalisability of the results cannot be guaranteed. The small sample applied to the current study cannot be tested for representativeness within the UK. In addition, systematic cross-cultural differences warrants care in generalisation beyond the UK. For example, US citizens have been reported as being more pro-technology compared to Europeans who are more concerned about the impact of nanotechnology on the environment and have less confidence in regulation (Gaskell et al., 2005). Thus results obtained in one country may not be applicable to populations in another. Future research, using a larger more representative sample to validate the current determinants as those of importance within the UK, or even generalising the conclusions by expanding to other cultures is required to make claims that the identified determinants of attitude towards nanotechnology are similar across consumers in many countries.

5.5 Conclusions

Lay people may differentiate nanotechnology applications based on the extent to which they are perceived to be beneficial, useful, necessary, and important. The extent to which they elicit fear and ethical concerns will reduce acceptance. The availability of alternative technological approaches to product development may militate against acceptance of products developed from nanotechnology if these are perceived to be less risky. Food applications of nanotechnology are seen to be beneficial and necessary, which contradicts several earlier studies as well as expert views regarding the relative acceptance of different applications.

CHAPTER 6

Consumer opinions regarding different applications of nanotechnology applied to food production

Abstract

Nanotechnology is increasingly being applied in the agri-food sector. Consumer attitudes will influence the development and commercialisation of agri-food applications of nanotechnology. Different socio-psychological factors have been identified which influence consumer acceptance of novel food technologies which may also be relevant to nanotechnology. The present study examined consumer opinion on agri-food applications of nanotechnology in the UK ($N = 417$), and determined the importance of different attitudinal constructs and perceptions on acceptance of agri-food applications of nanotechnology. Participants received information about nanotechnology in general and about three specific food related applications of nanotechnology: smart pesticides; nanoencapsulated-food ingredients and food packaging. The results suggest that the established determinants risk and benefit perceptions, as well as perceived need and fear, are relevant in influencing consumer responses. In addition, the potential for misuse/abuse of nanotechnology, the availability of equally effective (and potentially less risky) technologies to achieve the same goals, the extent to which nanotechnology applications will be "oversold" by innovators in terms of the benefits they will potentially deliver, and accessibility to nano-products also influence consumer attitudes. Risk and concerns about technological implementation emerged as the most important factors in determining successful introduction of nanotechnology, followed by benefits. Food packaging is perceived more positively than nanoencapsulated food ingredients and smart pesticides.

6.1 Introduction

Public acceptance is important for the success of any new technology as it will determine its subsequent development and commercialisation (see, inter alia, Frewer et al., 2013b; Gaskell et al., 1999). Food technology in particular has often been associated with negative societal responses in the past. Controversial technologies such as genetic modification (GM) applied to food production, and food irradiation have resulted in public concern in many parts of the world (Brewer and Prestat, 2002; Bruhn, 1995; Gaskell et al., 1999). It is important to note that there are, however, also examples of food technologies which do not appear to be associated with negative public response such as high pressure processing or nutrigenomics (Frewer et al., 2011a; Stewart-Knox et al., 2013), and technological innovation in the agrifood sector in itself may not result in societal negativity. Rather this is linked to perceptions and attitudes specifically linked to technologies and/or their applications.

Nanotechnology is an emerging technology that is being increasingly employed in the agri-food sector (Kuzma et al., 2008; Sanguansri and Augustin, 2006). In primary agricultural production, applications of nanotechnology are varied and diverse (Frewer et al., 2011c). For example, nano-based pesticides are being developed which have the capacity to enhance the efficacy and delivery of pesticides (Silva et al., 2011). Nanotechnology is also being used in food processing. For example, nanoscale food additives are used to change food texture, flavour, nutrient composition and product shelf life (Ravichandran, 2010). Encapsulation of nutrients at the nanoscale (Ezhilarasi et al., 2012) offers advantages for targeted site-specific delivery of nutrients and efficient absorption through body cells (Chen et al., 2006). Food packaging incorporating nano-composites is being developed to enhance the mechanical, barrier and antimicrobial properties of the packaging material (Chaudhry et al., 2008; Lagarón et al., 2005). A more recent development is intelligent packaging that incorporates nanosensors which can, for example, provide indication of spoilage of foods within the package (Neethirajan and Jayas, 2011).

Some concerns regarding adverse health and environmental effects associated with exposure to nanomaterials from consumer products have been raised, especially in relation to their impact on health and environmental safety (Borm et al., 2006; Buzby, 2010; Chau et al., 2007; Chaudhry et al., 2008; Handy et al., 2008; Klaine et al., 2008; Oberdörster et al., 2007; Wiesner et al., 2009). Earlier studies on consumer acceptance of nanotechnology have shown that food-related applications in general are viewed less positively, or at least differently, to other application areas of nanotechnology (Cobb and Macoubrie, 2004; Siegrist et al., 2007a). Therefore exploring consumer acceptance of agri-food applications is of particular interest, in particular because, in the past, more consumer concern has tended to be associated with applications of novel technologies in the agri-food domain compared to other domains of application of novel technologies (Cardello, 2003; Frewer et al., 2011a). A case in point is consumer rejection of applications of genetic modification (GM) when applied to food production (Gaskell et al., 2000). For example, applications of GM were seen as riskier, less beneficial and more ethically objectionable when applied to food production than medicine (Frewer and Shepherd, 1995). Some researchers have drawn analogies between agri-food applications of nanotechnology and GM food technology, assuming that agri-food applications of nanotechnology may follow similar commercialisation trajectories and therefore similar societal concerns (Cushen et al., 2012; Gupta et al., 2012b; Kearnes et al., 2006; Mehta, 2004; Rollin et al., 2011).

Research suggests that public acceptance of new food technologies is influenced by a number of socio-psychological factors that increase the likelihood of rejection or acceptance (see chapter 2; Gupta et al, 2012a, also see Siegrist, 2008). More specifically, public responses are likely to be contingent on both benefit and risk perceptions associated with specific food applications (Frewer et al., 1998b; Saba et al., 2003; Siegrist, 2000, 2008). Research on public acceptance of food applications of nanotechnology has highlighted the importance of risk-benefit perception (Siegrist et al., 2007a; Siegrist, 2008). Fear (Fife-Schaw and Rowe, 1996; Laros and Steenkamp, 2004; Slovic et al., 1980) and perceived need (Frewer et al., 1997) are also considered important factors determining consumer acceptance of novel food technologies, including nanotechnology. In addition, ethical and moral considerations influence public acceptance of novel food technologies (Frewer et al., 1997, 1994; Miles and Frewer, 2001; Sparks et al., 1995). These considerations are also shown to be important for nanotechnology, for example, as feelings of vulnerability and social justice (Burri and Bellucci, 2008; Conti et al., 2011); the potential for misuse of nanotechnology, and access to the benefits of nanotechnology by the public (chapter 5 of this thesis). In addition to these determinants, additional psychological factors that are specifically relevant to consumer acceptance of nanotechnology applications were identified in chapter 5. These include the availability of (potentially less controversial) alternative technologies to deliver the same benefits, doubt as to whether the technology will "perform as promised", and consumer concern about coming into physical contact with nanomaterials. While previous research on the perception of novel technologies has frequently examined underlying factors that determine public perception, there has been much less attention to the extent to which consumers assign importance to each factor. Although the importance of beliefs on a specific factor have long been accepted as an essential part in predicting attitudes (cf. Fishbein and Ajzen, 1975), research which attempts to assess the relative influence of different perceptions on acceptance has been infrequent.

Besides identifying a range of psychological determinants of technology acceptance, research on acceptance of new food technologies has also shown that socio-demographic characteristics, such as age, gender and education level influence individual acceptance of food technologies (De Jonge et al., 2004; Dosman et al., 2001; Miles et al., 2004). In addition, knowledge about food risks and nanotechnology may influence consumer view on nanotechnology (Vandermoere et al., 2011). Public trust in different information sources is also likely to shape consumer opinions regarding new food technologies, particularly when public knowledge about the associated risks and benefits is low (Frewer et al., 1996; Frewer and Shepherd, 1995).

The research presented here was conducted with two aims. The first was to determine the importance of different attitudinal constructs and perceptions identified in the literature on acceptance of different agri-food applications of nanotechnology. The second was to explore whether differences in perceptions are indicative of different socio-demographic profiles and level of trust in information provided by different actors.

6.2 Method

Participants & Data collection

Data were collected using an online questionnaire survey conducted in the UK between 5-28 September, 2012. Participants were quota sampled to be nationally representative on age, gender and education. Four hundred and seventeen people participated in the study. Fifty-five % ($N = 230$) of the respondents were women, and 45% ($N = 187$) were men. 41% ($N = 171$) of the participants were aged between 35 to 54 years; 22% ($N = 90$) were between 26-34 years; 16% ($N = 68$) between 55-65 years; 15% ($N = 61$) between 18-25 years and 7% ($N = 27$) were over 65 years. Self-reported education level ranged from no qualification (11.5%; N = 48), vocational qualification (7.2%; $N = 30$), GCSE/O level (38.8%; N = 162), A level (19.2%; N = 80), Bachelor degree (15.6%; N = 65) and Post graduate degree (7.7%; N = 32).

Materials

A brief description of nanotechnology was presented to participants at the start of the questionnaire (Table 6.1). Three agri-food applications of nanotechnology were selected for the present study: smart pesticides; encapsulation and delivery of nutrients in food, and food packaging. These were shown to be differentiated in terms of consumer acceptance in previous research (from chapter 5). Detailed descriptions of the three agri-food applications of nanotechnology were provided in randomised order. After each description, thirteen questions were asked in order to investigate the influence of nine potential determinants of the acceptability of each application: perceived benefit; perceived risk; perceived need; worry over coming in contact with nanomaterials; fear; concerns about the potential of misuse or abuse of nanotechnology; concerns about inequalities across the population regarding access to the benefits; the availability of alternative technologies which could potentially deliver the same benefits; and doubt over the effectiveness of nanotechnology regarding societal responses to nanotechnology. Items were scored on 5 point scales, with an additional option of “no opinion”.

Items were constructed for the purpose of the survey, and were pretested with staff and students at Wageningen University. Four items were used to measure benefit perception: benefits to an average person in society; health benefits; personal benefits other than health and environment benefits (1 = extremely beneficial; 5 = not at all beneficial). Similarly risk perception was measured using four items: risks to an average person in society; health risks; personal risks other than health and environment risks (1 = extremely risky; 5 = not at all risky). Additional determinants were measured with single items: “how worried are you about coming into contact with the nanomaterials used in (*application*)” (1 = extremely worried about coming into contact; 5 = not at worried about coming into contact); “to what extent do you think it is likely that (*application*) developed using nanotechnology will be misused or abused” (1 = extremely likely; 5 = not at all likely); “to what extent do you think that it is likely everyone who wants (*application*) will be able to have access to them” (1 = extremely likely; 5 = not at all likely); “to what extent do you think the use of (*application*) developed using nanotechnology is needed” (1 = extremely necessary 5 = not at all necessary); “to what extent do you think the use of (*application*) developed using nanotechnology is frightening” (1 = extremely frightening; 5 = not at all frightening); “to what extent do you agree that there are other, equally effective technologies (other than nanotechnology) which can be used to improve (*application*)” (1 = agree strongly; 5 = disagree strongly); and “to what extent do you think that (*application*)will be oversold in terms of the benefits it will potentially deliver” (1 = extremely likely; 5 = not at all likely). The importance of each of the potential determinants was then rated, on a 5 point scale (1 = extremely important; 5 = not at all important).

Table 6.1. Descriptions of nanotechnology and 3 agri-food applications of nanotechnology

Nanotechnology	Nanotechnology is a technology that is based on the use of very small particles (nanoparticles). Nanoparticles are smaller than 100 nano meters. For comparison, a human hair is, on average, about 60,000 nanometres thick (in other words nanoparticles are very small indeed). One nanometre is only one-billionth of a meter in size. Nano particles can be used to design and deliver new applications of products and services, for example in medicine, cosmetics, materials engineering and food products.
Smart- pesticides	Smart pesticides are new generation of chemicals used for crop protection in agriculture. Pesticides are encapsulated using nanoparticles so to minimise the doses of pesticide which are used on the crop, and to get maximum effect with more targeted action of the pesticides.
Encapsulation and delivery of nutrients in food	Nanoparticles are used to "encapsulate" or enclose vitamins or other nutrients, and carry them through the stomach straight into the intestine to be absorbed by the bloodstream. This means they are not broken down in the stomach, and so can be used by the body to improve health.
Food packaging	Nanotechnology can be applied to develop synthetic food packaging that kills germs which cause foods to "go-off". This means that the food can be preserved for longer periods of time. The packaging is described as having "antimicrobial" properties

Trust in information about nanotechnology provided by 8 institutions: universities, industry, government/regulatory agencies, consumer organisations/public NGOs, environmental NGOs, patient groups, media and insurance companies was measured on a 5 point scale (1 = no trust at all to 5 = trust extremely high). Familiarity with, and knowledge, about nanotechnology was measured in two steps. Participants were first asked to indicate whether they were familiar with nanotechnology (before they participated in the study) (1 = Yes; 2 = No). If they answered yes, they were requested to indicate how knowledgeable they thought they were about nanotechnology on a 5 point scale (1 = extremely knowledgeable; 5 = not at all knowledgeable).

6.3 Results

Twenty-nine % ($N = 122$) of the participants indicated that they were familiar with nanotechnology before completing the questionnaire. The self-rated knowledge among the participants who were knowledgeable about nanotechnology ranged from extremely knowledgeable (2.2%; $N = 9$), very knowledgeable (3.4%; $N = 14$), moderately knowledgeable (7.9%; $N = 33$), slightly knowledgeable (14.4%; $N = 60$) and not at all knowledgeable (1.4%; $N = 6$).

Factors influencing public opinion on agri-food applications of nanotechnology

A principle component analysis (PCA) of the aggregated data of the nine candidate determinants, with Oblimin rotation was conducted. Based on the scree plot a four component solution was obtained that explained 77.3% of the variance (first five initial Eigen values being 6.28, 3.27, 1.26, 0.77 and 0.69). Six items that loaded on Principle component (PC) 1 were "personal risks", "general risks", "environmental risks", "health risks", "fear", and "worry over coming in contact with the nanomaterials". These six items showed a high internal consistency (Cronbach $\alpha = 0.94$) and were labelled as "**risk and fear**". Five items that loaded on PC2 were "personal benefits", "general benefits", "environmental benefits", "health benefits", and "need" (Cronbach $\alpha = 0.92$). The second factor was defined as "**benefits and need**". Items associated with PC3 were "availability of equally effective technologies other than nanotechnology", "potential of misuse/abuse of technology" and "the extent to which the nanotechnology application will be oversold in terms of the benefits it will potentially deliver" (Cronbach $\alpha = 0.68$).These items were averaged to form a third factor labelled as "**concerns about technological implementation**". PC4 had only one item "accessibility" that loaded on this factor. Therefore the fourth factor was labelled as "**access to technology**". Moderate correlation (was found between PC1 and PC3 (.47) and lower correlations were found between PC1 and PC2 (-.28); PC1 and PC4 (-.13); PC2 and PC3 (-.18); PC2 and PC4 (-.17) and PC3 and PC4 (-.23). All correlations were significant at alpha = .05.

The importance of the nine candidate determinants influencing introduction of nanotechnology was assessed using aggregated importance scores. Six items on importance of "personal risks", "general risks", "environmental risks", "health risks", "fear", and "worry over coming in contact with the nanomaterials" showed high internal consistency (Cronbach $\alpha = 0.93$) and they were aggregated together and labelled as "**importance of risk and fear**". Five items on the importance of "personal benefits", "general benefits", "environmental benefits", "health benefits", and "need" showed a high internal consistency (Cronbach $\alpha = 0.92$) and were labelled as "**importance of benefits and need**". Three items assessing the importance of "availability of equally effective technologies other than nanotechnology", "potential of misuse\abuse of technology" and "extent to which the nanotechnology application will be oversold in terms of the benefits it will potentially deliver" had high internal consistency (Cronbach $\alpha = 0.88$).These items were averaged and labelled as "**importance of concerns about technological implementation**". The single item measuring importance of "accessibility" did not show high consistency with any of the other items and therefore was labelled as "**importance of access to technology**".

Public perception of agri-food applications of nanotechnology

ANOVA indicated a significant main effect of nanotechnology application for all four factors: "risk and fear" ($F(1.96,726.80) = 12.70$; $p < .001$); "benefits and need" ($F(1.92, 701.81) = 6.05$; $p < .001$); "concerns about technological implementation" ($F(1.96,706.93) = 8.85$; $p < .001$) and "access to technology" ($F(1.96,587.72) = 19.01$; $p < .001$), indicating the products score differently on all four determinants. Pairwise comparisons (LSD) between applications (Table 6.2) showed that of the three agri-food applications, participants perceived smart pesticides as the most, and food packaging as the least risky and frightening application. Participants rated smart pesticides as least beneficial and perceived the application to be least necessary of all the applications. In contrast, food packaging was perceived to be most beneficial and necessary. In terms of concerns about technological implementation, participants indicated that these will be greatest for nanoencapsulated food ingredients and least for food packaging. Participants perceived that nanoencapsulated food ingredients will be least accessible to the consumers who need them, while food packaging would be most accessible.

A repeated measures ANOVA indicated a significant main effect influencing importance of those factors for societal introduction of nanotechnology, $F(1.87, 776.30) = 47.70$; $p < .001$. Pairwise comparisons (LSD) of the importance of the 4 factors indicated that risk and fear and concerns about technological implementation are the most important factors influencing consumer acceptance of different applications of nanotechnology followed by "benefits & need". The issue of accessibility of nano-products is rated as the least important factor influencing acceptance (Table 6.2).

Table 6.2. Descriptions of nanotechnology and 3 agri-food applications of nanotechnology

Factors[1]	**Smart pesticide**	**Nano - encapsulated food**	**Food packaging**	**Importance of factor for introduction of nanotechnology** (1 = extremely important, 5 = not at all important)[2]
Concerns about technological implementation (1 = extremely likely to raise concern, 5 = not at all likely to raise concern)[1]	2.80 (.05)[a]	2.78 (.05)[a]	2.95 (.05)[b]	2.26 (.05)[I]
Benefits and Need (1 = extremely beneficial and necessary, 5 = not at all beneficial and necessary)[1]	3.16 (.06)[a]	3.01 (.06)[b]	2.97 (.06)[b]	2.60 (.05)[II]
Access to technology (1 = extremely likely to have access, 5 = not at all likely to have access)[1]	3.30 (.06)[a]	3.37 (.07)[a]	2.98 (.07)[b]	2.81 (.06)[III]
Risk and Fear (1 = extremely risky and frightening, 5 = not at all risky and frightening)[1]	3.57 (.05)[a]	3.71 (.05)[b]	3.79 (.06)[b]	2.27 (.05)[I]

[1] Means with a different character are significantly different between applications or factors (pairwise comparisons LSD; $\alpha = .05$)

[2] Means with a different Roman numeral are significantly different between applications or factors (pairwise comparisons LSD; $\alpha = .05$)

Trust in information on nanotechnology provided by different institutions

A repeated measures ANOVA indicated a significant main effect of different institutions influencing trust in information regarding nanotechnology ($F(4.70, 1953.17) = 186.44$; $p < .001$). Pairwise comparisons (LSD) between institutions show that participants indicated high trust in universities compared to other institutions. This is followed by patient groups, NGOs (public and environment), government/regulatory agencies and industry. In comparison, participants distrusted insurance companies and the media the most (Table 6.3).

Table 6.3. Estimated marginal mean scores (Standard errors) of trust in information based on repeated measures ANOVA

Institutions	**Trust in information** (1 = No trust at all, 5 = extremely high trust)[1]
Universities	3.29 (.05)[a]
Industry	2.51 (.05)[b]
Government/ Regulatory agencies	2.61 (.05)[b]
Consumer organisations/ Public NGOs	3.03 (.05)[c]
Environmental NGOs	3.01 (.05)[c]
Patient groups	3.04 (.05)[c]
Media	1.97 (.05)[d]
Insurance companies	2.01 (.05)[d]

[1] Means with a different character are significantly different between applications or factors (pairwise comparisons LSD;$\alpha = .05$)

Participant segmentation

Cluster analysis was applied to the aggregated data regarding different factors and their importance in order to identify different groups of participants. Ward's method consisting of a hierarchical cluster analysis to determine the number of clusters followed by K-means cluster to determine cluster membership was used to determine the number of clusters. Of the total 417 participants, 125 (30%) participants selected "don't know" option in either of the three food applications, leaving 292 participants that could be grouped into different clusters. Three clusters were identified that significantly differed on overall "risk and fear" ($F(1.94,560.62) = 5.16$; $p < .01$) and "access to technology" ($F(1.96,567.18) = 16.62$; $p < .001$) but not on overall "benefits and need" ($F(1.93,558) = 2.16$; $p = .12$) and "concerns about technological implementation" ($F(1.95,564.27) = 1.81$; $p = .30$) factors. There were sufficient participants in each cluster: cluster 1: $N = 145$ (35%); cluster 2: $N = 60$ (14%); cluster 3: $N = 87$ (21%) to allow interpretation of the clusters. In addition to cluster variables (factors influencing societal response and the importance of these factors in the societal introduction of nanotechnology), interpretation variables including socio-demographic variables (gender, age and level of education), knowledge variables (familiarity and self-reported knowledge level) and trust in information about nanotechnology provided by different institutions were also used for interpretation of the identified clusters (Table 6.4).

Members of cluster 1 emerged as more neutral/moderate group on their opinion about nanotechnology. They perceived agri-food applications of nanotechnology to be slightly risky and moderately beneficial and necessary. Participants in this cluster perceived that there is some likelihood for agri-food applications to be misused/abused and to be oversold in terms of the benefits they will deliver. They believed that the benefits of the products would not be accessed by the public, and were not sure whether equally effective technologies were available. In terms of importance of different factors, members of this cluster indicated that benefits and need were very important while other 3 factors: risk and fear; concerns about technological implementation and accessibility were somewhat important. Members of cluster 2 were more negative about food applications of nanotechnology, and were labelled as "risk averse", perceiving all applications to be very risky with few benefits, unnecessary, likely to be misused and oversold in terms of their benefits. They were also of the opinion that there is only a moderate likelihood that people would have access to such products. Members of cluster 2 also moderately agreed that there were other equally effective technologies available. In terms of importance of different factors in successful introduction of nanotechnology, they rated risk and fear and concerns about technological implementation as extremely important factors determining successful introduction of nanotechnology, while the equitable access to the benefits of the technology was slightly important and benefits and need were considered to be somewhat important. In contrast, members of cluster 3 rated applications as very beneficial and necessary with moderate risks. In terms of concerns about technological implementation, they indicated that there was a moderate likelihood of nanotechnology being misused/ abused and products being oversold in terms of the benefits. They neither agreed nor disagreed that other technologies could be used to obtain the same ends and were optimistic about the accessibility of such products to the general public. Participants in this cluster indicated that all factors would be very important for successful introduction of nanotechnology.

The demographic differences between these clusters were not major. There were no significant differences based on gender and level of education. The clusters differed significantly based on age of the participants ($\chi^2(8, N = 292) = 19.07$, $p < .05$). Members of cluster 1 tended to be younger and middle aged, with fewer older participants, while members of cluster 2 tended to be from the middle age group (35 – 54 years) and older (55 – 65 and 65+). Cluster 3 tended to have younger participants (18 – 25 and 25 – 35 years). The clusters were also found to differ significantly on self-reported knowledge level ($F(2,100) = 18.68$; $p < .001$). Members of cluster 1 and 2 were "slightly knowledgeable" and members of cluster 3 were "very knowledgeable" about nanotechnology. Trust in information varied among the different clusters ($F(4.87,1408.45) = 135.89$; $p < .001$). Members of cluster 1 had moderate trust, members of cluster 2 had less trust and members of cluster 3 hade more trust in information on nanotechnology provided by different institutions.

Table 6.4. Participant segmentation based on their views on different factors ($N = 292$)

		Cluster 1 Moderate/ Neutral	**Cluster 2** Risk Averse	**Cluster 3** Benefit Seekers	**Repeated Measures ANOVA**
N		145	60	87	
Clustering Variables					
Risk - fear	Smart-pesticides	3.9	2.8	3.4	Interaction effect: $F(3.88{,}560.62) = 1.27$; $p = .28$
	Nano-encapsulated food	4.1	2.9	3.4	
	Food packaging	4.2	2.9	3.4	
	Overall	4.1	2.9	3.4	Main effect: $F(1.94{,}560.62) = 5.16$; $p < .01$
	Importance	2.7	1.7	1.9	$F(2{,}289) = 36.42$; $p < .001$
Benefit-Need	Smart-pesticides	3.2	4.1	2.2	Interaction effect: $F(3.86{,}558) = 3.78$; $p < .01$
	Nano-encapsulated food	2.9	4.1	2.1	
	Food packaging	2.8	4.3	2.2	
	Overall	3.0	4.1	2.1	Main effect: $F(1.93{,}558) = 2.16$; $p = .12$
	Importance	2.6	3.2	1.9	$F(2{,}289) = 51.8$; $p < .001$

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Table 6.4 – *Continued from previous page*

		Cluster 1 Moderate/ Neutral	**Cluster 2** Risk Averse	**Cluster 3** Benefit Seekers	**Repeated Measures ANOVA**
Concerns about technological implementation	Smart-pesticides	3.1	2.1	2.6	Interaction effect: $F(3.91,564.27) = 3.98$; $p < .01$
	Nano-encapsulated food	3.2	2.1	2.6	
	Food packaging	3.5	2	2.6	
	Overall	3.3	2.09	2.6	Main effect: $F(1.95,564.27) = 1.81$; $p = .30$
	Importance	2.7	1.7	1.9	$F(2,289) = 40.26$; $p < .001$
Accessibility to technology	Smart-pesticides	3.7	3.4	2.5	Interaction effect: $F(4,567.18) = 0.59$; $p = .67$
	Nano-encapsulated food	3.8	3.5	2.6	
	Food packaging	3.4	3	2.3	
	Overall	3.6	3.3	2.4	Main effect: $F(1.96,567.18) = 16.62$; $p < .001$
	Importance	2.8	3.5	1.9	$F(2, 289) = 49.09$; $p < .001$
Interpretation variables					
Gender(% female)		53%	58%	44%	$\chi^2(2,N = 292) = 3.4$, $p = .18$

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Table 6.4 – *Continued from previous page*

		Cluster 1 Moderate/ Neutral	**Cluster 2** Risk Averse	**Cluster 3** Benefit Seekers	**Repeated Measures ANOVA**
Age	18-25	14.5%	10.0%	20.7%	$\chi^2(8, N = 292) = 19.07$, $p < .05$
	26-35	20.0%	11.7%	28.7%	
	35-54	46.9%	51.7%	29.9%	
	55-65	15.9%	23.3%	12.6%	
	65+	2.8%	3.3%	8.0%	
Education Level	No formal qualification	6.9%	8.3%	12.6%	$\chi^2(10, N = 292) = 11.07$, $p = .35$
	Vocational qualification	6.2%	3.3%	11.5%	
	GCSE/O Level	40.0%	38.3%	32.2%	
	A level	24.1%	23.3%	13.8%	
	Bachelor Degree	13.8%	18.3%	19.5%	
	Post graduate Degree	9.0%	8.3%	10.3%	
Familiarity at all (% yes)		30%	43%	39%	$\chi^2(2, N = 292) = 4.26$, $p = .12$
Knowledge		$(N = 43)$3.7	$(N = 26)$ 3.6	$(N = 34)$2.6	$F(2,100) = 18.68$; $p < .001$
Trust		2.73	2.50	3.03	$F(4.87,1408.45) = 135.89$; $p < .001$

6.4 Discussion

Consumer response to different agri-food applications of nanotechnology is likely to be influenced by a number of factors. This research showed that established determinants of acceptance, such as risk and benefit perceptions, as well as perceived need and fear, influence consumer response to agri-food applications of nanotechnology. In addition factors such as the potential for misuse/abuse of nanotechnology, the availability of equally effective (and potentially less risky) technologies other than nanotechnology to achieve the same goals, the extent to which nanotechnology applications will be oversold in terms of the benefits they will potentially deliver, and accessibility to nano-products would also influence consumer attitudes. The factor structure obtained in the present study is similar to the factor structure seen in chapter 5 that used a small sample of participants in the UK. The majority of the participants reported being unfamiliar with nanotechnology and its applications, an observation reported in previous research (Pidgeon et al., 2009; Satterfield et al., 2009; Vandermoere et al., 2011).

Participants in this study differentially rate the importance of the different factors identified. Risk and concerns about technological implementation emerged as the most important factors in determining successful introduction of nanotechnology followed by benefits. These differences indicate that consumers weigh the perceived benefits and risks differently for nanotechnology in the agri-food sector, which is consistent with prospect theory which also shows a higher weighing of risks compared to benefits in conditions of uncertainty (Kahneman and Tversky, 1979). Framing of specific situations may account for the differential weighing of risk and benefits, where consumers are shown to be more accepting towards risks when a situation is framed as reduction of a loss, while they become risk-aversive when the outcome is framed as a gain. Nanotechnology applications in the agri-food domain are framed as improved nutrition and quality for a product that already has sufficient quality and nutrition from a consumer's point of view, and, thus is framed as an increase in gains, with very small benefits indeed. This would bring consumers in a risk averse frame, meaning that even small perceived risks may lead to low acceptance. In this case future consumer acceptance of agri-food applications of nanotechnology may be improved by framing the benefits in terms of reduction of potential food risks instead of solely advertising them in terms of enhanced nutrition or quality, or alternatively by creating considerably more substantial end-user benefits than in the applications tested in the current study in order to offset the activated risk aversion motivation.

The three agri-food applications of nanotechnology were rated differently. Use of nano-pesticides was considered risky and frightening, while food packaging was perceived as the most beneficial, necessary and accessible product. Participants indicated that there will be concerns about technological implementation and lack of consumer access to the benefits of encapsulation and delivery of nutrients in food using nanotechnology, in line with earlier research (Siegrist et al., 2007b, 2008b). The results suggest that consumers tend to assess consumption of nanoparticles in food as relatively risky compared to those which are not consumed in food. However, pesticides were regarded as even riskier. This shows that the presence of nanoparticles in product does not give full account of risk perception, but that other negative associations carried by the application as in the case of pesticides (Ahmed et al., 2011; Bruhn et al., 1991; Harris et al., 2001) also contribute to consumer perceptions of a specific application. Based on this result it can speculated that application of novel technologies such as nanotechnology can be perceived as more risky if applied within already controversial application areas.

Levels of trust in information on nanotechnology varied for different institutions. Participants had high trust in the information provided by universities and patient groups and NGOs (consumer and environmental) and less trust in information provided by the media. This result may have implications for future benefit-risk communication concerning agri-food applications of nanotechnology as information sources that are trusted more by the public are more likely to influence public opinion on nanotechnology while communication done via channels or sources that are distrusted by the public will not affect public opinion on nanotechnology. Low trust in information by the media could be attributed to recent media scandals that have occurred in the UK, limiting these conclusions specific to the current UK context. To what extent these specific situations can be generalised beyond the current time can only be determined through cross cultural comparisons or longitudinal research in trust development in the UK.

In the current study, three different groups of consumers were identified: those who could be described as benefit seekers; those who are risk averse; and a moderate/neutral group. Participants perceiving more benefits had low risk perceptions of the different applications of nanotechnology and *vice versa*. It is, however, important to note that in the present study about half the people take a neutral/moderate stand on agri-food applications of nanotechnology indicating a large group that has neither a positive or negative opinion in the current context. A further 30% of the participant had no opinion on these applications. These outcomes are similar to previous research conducted in the UK in 2007 (Fischer et al., 2012), implying that in the five years between 2007 and 2012 little crystallization of opinions on nanotechnology has occurred.

One caveat to the interpretation of these results needs to be mentioned. When choosing food in a real context, people often depend on personal experience, rather than the description of the product. In this case, participants had to rely fully on the description of the different applications provided, which are not yet available in the market. Therefore the current research may not fully translate into real behaviours. Future studies need to be undertaken to study public perception of real agri-food applications of nanotechnology, especially when more agri-food applications of nanotechnology become available in the market, and when explicit labelling policies regarding inclusion of nanoparticles in products are in place (Gruére, 2011), as nano ingredients in food may then become salient to food consumer.

The determinants of consumer acceptance identified in the current study are also likely to discriminate between different consumers regarding acceptance of different applications of agri-food technology, and may also be considered in the development of communication about the benefits and risks of different applications, using a case-by-case approach.

CHAPTER 7

General Discussion

The current thesis was initiated from the position that predicting potential societal responses to novel and emerging technologies is an important factor in predicting the success or failure of the commercialisation of their applications (Cameron, 2006; Frewer et al., 2004). Nanotechnology represents an emerging enabling technology that can be applied across a broad range of application areas such as medicine, agriculture, chemical synthesis, industrial manufacturing, and environmental remediation. As indicated throughout the thesis, many important stakeholders in society have posited that societal reactions to other emerging technologies, in particular more recently developed and applied exemplars such as genetic modification (GM) applied to agri-food production, represent the normative societal response to *all* emerging technologies. For this reason it is important to contextualise *potential* societal responses to nanotechnology by considering *previous* societal responses to technologies which have already been applied. In this thesis, the primary aim was to compare expert views with those held by the general public regarding the likely societal response to implementation of different applications of nanotechnology. This comparison was important as the opinions of experts and lay people are likely to be formed by different factors and considerations. The commercialisation trajectory of different nanotechnology applications is likely to be driven by the opinions of experts regarding societal acceptability of these. If expert views of societal acceptability do not align with those held by the general public, applications that consumers will reject may be introduced initially, and focus public opinion on the negative aspects of nanotechnology. Conversely, applications which are acceptable to consumers may never be commercialised if experts perceive that consumers are likely to reject them. The results provide evidence on which a future commercialisation trajectory for nanotechnology can be developed.

In this thesis, candidate "drivers" or determinants of societal responses to nanotechnology have been identified and evaluated in terms of their importance in shaping societal introduction of nanotechnology (Table 7.1). Three research approaches were utilised to meet these aims. The first focussed on reviewing previous scientific research into the socio-psychological factors that influence public acceptance of new technologies. The second focussed on identifying and quantifying expert views on the factors that will influence societal acceptance or rejection of nanotechnology. The third tested whether the different factors do, in fact, drive public opinion. In this final chapter, the three perspectives will be integrated to deliver evidence which can be used to formulate policy regarding future implementation and commercialisation trajectories for different types of nanotechnology application. In addition, the implications for research into societal response to nanotechnology will be discussed, together with the limitations associated with the research presented here, and suggestions for future research are made.

7.1 Summary and conclusions

Socio-psychological determinants of public acceptance of new technologies: A literature review

In chapter 2 of the thesis, socio-psychological determinants of public acceptance of new technologies were identified through analysis of the literature on social psychology and risk perception. Ten controversial technologies of relevance to understanding public acceptance of technologies were included in this review. Thirty one potential factors were found to potentially influence public acceptance of new technologies. The factors most frequently addressed by researchers included perceived risk, trust and culpability, perceived benefit, and citizens' knowledge, although other factors were also found the topic of research. Individual differences related to socio-demographic factors were also reported to be relevant for predicting peoples' attitudes towards new technologies. The results showed that some factors, (such as risk and benefit perceptions), have been used more extensively to explain peoples' reactions to specific technologies. For example, perceived environmental impact and ethical concerns have less frequently been researched as potential determinants of technology acceptance or rejection. Nanotechnology was identified as a potentially societally controversial emerging technology, with relatively strong associations with perceived risk and benefit. However, some determinants of societal response were reported to be specific to nanotechnology. The relatively modest amount of literature on societal responses to specific applications of nanotechnology is an area which will require further research, as public attitudes are shaped by perceptions of risk and benefit, and other psychological factors, associated with specific applications. Public attitudes will influence consumer acceptance of different applications, which in turn will influence which nanotechnology applications are developed and commercialised in the future. This is likely to be particularly true in relation to specific application domains, for example, agrifood production or medicine. The need to assess the importance of different cultural contexts as potentially influential factors in determining consumer acceptance was identified in chapter 2, as existing research has predominantly been conducted in Northern America and Europe.

Expert opinions regarding factors influencing societal response to different applications of nanotechnology

Chapter 3 explores expert opinions regarding what factors may potentially influence societal response to 15 different applications of nanotechnology drawn from varied areas of application (e.g. medical, agricultural, environmental, military, sport- related etc.). The repertory grid method in combination with generalised Procrustes analysis was applied to structured interviews which were conducted using with seventeen experts from North-West Europe. This methodology allowed the experts to express the factors which will potentially influence societal responses to different applications of nanotechnology using their own words, avoiding researcher bias in deciding what questions were relevant and should be asked. Experts perceived that the main factors influencing societal responses to different applications of nanotechnology were the extent to which applications are perceived to be beneficial, useful, and necessary, and the extent to which these applications will be perceived as "real" and physically close to the end-user. Perceived risk was less frequently mentioned by experts as a potential factor influencing societal acceptability. Experts indicated that medical nanotechnology applications (targeted drug delivery) and environmental nanotechnology applications (water filtration) will be the most societally acceptable. In contrast, agrifood applications (smart pesticides, nano-encapsulated food and food packaging) will be the least societally acceptable.

Chapter 4 further investigates the factors which experts perceive may differentiate different applications of nanotechnology in terms of social acceptance and rejection by utilising a larger and more diverse sample of experts. Experts from Northern America, Europe, Australasia, India and Singapore were asked to rate the relative importance of the different factors driving societal acceptance of (different applications of) nanotechnology within different technological environments, consumer cultures and regulatory regimes (see also chapter 2). Experts were asked to compare five applications of nanotechnology (targeted drug delivery, water filtration, smart pesticides, nanoencapsulated food and food packaging) in terms of the factors driving consumer acceptance. The results suggested that experts thought that perceived risk and consumer concerns regarding contact with nano-particles would lead to public rejection of nanotechnology applications, and perceived benefits would influence societal acceptance. The results were not highly differentiated across different countries, with the exception of India, where perceived risks were considered less relevant compared to the other countries. Encapsulation and delivery of nutrients in food was thought to be the application most likely to raise societal concerns, while targeted drug delivery was thought most likely to be accepted.

Consumer perception regarding the factors influencing societal response to different applications of nanotechnology

Chapter 5 explores the factors influencing consumer opinion regarding which factors influence societal responses to the same 15 key applications of nanotechnology used in chapter 3. Structured interviews with participants in the UK suggested that consumers differentiate nanotechnology applications based on the extent to which they perceive them to be *beneficial, useful, necessary* and *important*. The results also suggest that negative public reactions will be driven by *perceptions of fear, concerns about privacy, ethical concerns, and perceived* equity regarding to whom the benefits of nanotechnology products will accrue. Of the 15 applications, medical and environmental applications were perceived as the most beneficial, an issue on which experts and consumers agreed. In contrast to the views of experts (chapter 3) food applications were rated as generally beneficial. Consumer perceptions differed from those identified as being influential by experts, insomuch that consumers emphasized fair distribution of benefits as being a determinant of acceptance, but had fewer concerns regarding the potential for physical contact with products made using nanotechnology, and the time to market introduction of nanotechnology products.

Chapter 6 of this thesis focuses on consumer opinions regarding different applications of nanotechnology applied to food production (smart pesticides; nanoencapsulated-food and food packaging). These areas of application are those where consumer opinion differed most when compared to that expressed of experts. The aim was to determine the relative importance of different attitudinal constructs and perceptions identified in the literature, and relate these to the factors identified in chapter 5. A consumer survey, conducted in the UK, showed that risk and benefit perceptions, as well as perceived need and fear, influenced consumer response to agrifood applications of nanotechnology. Perceived risk, although not identified as important in either of the repertory grid studies, was included in the survey as it has been identified as important both in the literature (Chapter 2) and in the expert survey. The consumer survey showed that, when asked about potential risks, consumers rate these as being relevant in determining consumer acceptance. A question arises as to whether asking the question about risk has induced consumer awareness and concern where it did not exist before. In addition, the perceived potential for misuse/abuse of nanotechnology, the perceived availability of equally effective (and potentially less risky) technologies other than nanotechnology to achieve the same goals, the extent to which nanotechnology applications will be "oversold" by industry and scientists, the extent of potential benefits the applications will deliver, and accessibility to the products of nanotechnology also influence consumer opinion. Interestingly, perceived risk and concerns about technological implementation emerged as the most important factors in determining successful introduction of nanotechnology. Perceived benefit was also rated as important, but less than perceived risk. Food packaging was perceived to be less risky than nanoencapsulated-foods and smart pesticides.

Table 7.1. Factors influencing societal response to different applications of nanotechnology

Literature Review (Chapter 2)				
Factors	**Indicators**	**Corresponding technologies**		**Importance**
Perceived Benefits	Not applicable (NA)	ICT, nanotechnology, hydrogen power & GM		NA
Perceived Risks	NA	Nuclear technology, RFID		NA
Trust	NA	ICT, nanotechnology, hydrogen power & GM		NA
Citizen Knowledge	NA	ICT, nanotechnology, hydrogen power & GM		NA
Individual differences	NA	ICT, nanotechnology, hydrogen power & GM		NA
Attitude	NA	Nuclear technology, RFID, ICT, nanotechnology, hydrogen power & GM		NA
Expert Opinion Repertory grid study (N = 17) (Chapter 3)				
Factors identified	**Indicators**	**High scoring applications**	**Low scoring applications**	**Importance****
PC 1: Beneficial, Useful & Necessary	*acceptable to society; environmental benefits; general benefits; perceived general benefits; human health benefits; larger socioeconomic benefits; consumer choice available; necessary; useful*	targeted drug delivery, neuro-implantable devices, water filtration, soil-water remediation, chemical sensors & fuel cells	smart pesticides, smart dust, RFID tags, nanofabrics, cosmetics & sports goods	High
PC 2: Beneficial	*general benefits; environmental benefits; human health benefits; low general risk; outside body/food chain; perceived general benefits; acceptable to society*	targeted drug delivery, neuro-implantable devices, water filtration, soil-water remediation, chemical sensors & fuel cells	smart pesticide, smart dust, food packaging, nano-encapsulated food, RFID tags & cosmetics	Medium
PC 3: Distance from end-user	*acceptable to society; does not come in contact with public; environmental benefits; low general risk; outside body/food chain*	RFID tags, soil-water remediation, water filtration, chemical sensors & fuels cells	smart dust, neuro-implantable devices, smart pesticides, nano-encapsulated food, cosmetics & targeted drug delivery	Medium
PC 4: Real & personal benefits	*consumer choice available; perceived general benefits; personal benefits; real; human health benefits*	sports goods, easy to clean surfaces, nanofabrics & cosmetics	Smart pesticide, smart dust & neuro-implantable devices	Low

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Table 7.1 – *Continued from previous page*

Expert Opinion Survey ($N = 67$) (Chapter 4)				
Factors identified	**Indicators**	**High scoring applications**	**Low scoring applications**	**Importance***
Perceived benefit	NA	targeted drug delivery & water filtration	Nano-encapsulated food	Fairly high
Perceived risk	NA	nano-encapsulated food & smart pesticides	targeted drug delivery & water filtration	High
Necessity	NA	targeted drug delivery & water filtration	nano-encapsulated food	Low
Consumer concern regarding contact with nanomaterials	NA	smart pesticides & nano-encapsulated food	water filtration, food packaging & targeted drug delivery	Fairly low
Time frame for commercialisation of the nano product (products to come soon in market)	NA	water filtration & food packaging		No consensus
Consumer Opinion Repertory grid study ($N = 18$) (Chapter 5)				
Factors identified	**Indicators**	**High scoring applications**	**Low scoring applications**	**Importance****
PC 1: General benefits to society - Fear, risk, ethical concern and uncertainty regarding who benefits continuum	*beneficial for more people; general benefits; daily use; desired by everyone; environmental benefits; health benefits; makes lifestyle easy; necessary; useful for general public; could be misused/abused; doubts; fear; generally fewer or no benefits; no knowledge; not acceptable to society; less/not desirable; privacy concern; useful for subgroup of people*	water filtration, easy to clean surfaces, nanofabrics, nano-encapsulated food, food packaging, targeted drug delivery & environmental remediation	RFID tags, chemical sensors, brain implants, sports goods, smart pesticides & smart dust	High
PC 2: Personal benefits and need - lack of need continuum	*desired by everyone; health benefits; necessary; personal benefits; useful for general public; environmental benefits; generally fewer or no benefits; less/not necessary; less/not important; less/not desirable; useful for subgroup of people*	targeted drug delivery, brain implants, water filtration, nano-encapsulated food, food packaging, environmental remediation & cosmetics	nanofabrics, chemical sensors, fuel cells, sports goods, RFID tags, easy to clean surfaces, smart pesticides & smart dust	Medium

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Table 7.1 – *Continued from previous page*

PC 3: Important and/or necessary - only one of many alternatives available continuum	*beneficial for more people; general benefits; environmental benefits; health benefits; important; necessary; useful for subgroup of people; alternatives are available; doubts; less/not necessary; less/not important; nice to have; personal benefits*	water filtration, environmental remediation, targeted drug delivery, brain implants, chemical sensors, fuel cells & smart pesticides	smart dust, nanofabrics, cosmetics, RFID tags, easy to clean surfaces & sports goods	Low
Consumer Opinion Survey (N = 417) (Chapter 6)				
Factors identified	**Indicators**	**High scoring applications**	**Low scoring applications**	**Importance***
PC 1: Risk & Fear	*personal risks; general risks;environmental risks; health risks; fear*	smart pesticides	food packaging	High
PC 2: Benefits and Need	*personal benefits; general benefits; environmental benefits; health benefits; need*	food packaging	smart pesticides	Medium
PC 3: Concerns about technological implementation	*availability of equally effective technologies other than nanotechnology; potential of misuse/abuse of technology; extent to which the nanotechnology application will be oversold in terms of the benefits it will potentially deliver*	Nano-encapsulated food	food packaging	High
PC 4: Access to technology	*-Accessibility*	food packaging	Nano-encapsulated food	Low

** Importance of factors (based on explained variance)

* Importance of factors (reported)

7.2 Implications

Scientific & Policy Implications

In this thesis, public-expert comparisons are made by using several different approaches to address the primary research question (namely to identify factors which will potentially influence societal responses to nanotechnology). Expert views are likely to drive development and commercialisation of nanotechnology applications. Comparing expert views with those of consumers will facilitate identification of whether or not expert views align with those held by consumers. If non-alignment occurs, then potentially beneficial applications may not be developed because of misaligned fears about consumer rejection. In addition, applications that are likely to be rejected by the consumers may be commercialised which will potentially have negative impacts on the commercialisation of other applications of nanotechnology.

The combination of the literature review on determinants of public acceptance of new technology (chapter 2), and the empirical analysis of expert (chapters 3 and 4) and consumer (chapters 5 and 6) acceptance of nanotechnology allows for triangulation of results from different stakeholder perspectives. Table 7.1 provides an integrated overview of the results from the different studies.

From the four studies summarised in table 7.1, it becomes clear that both experts and consumers identified in common many factors which will potentially shape societal acceptance of nanotechnology. This might indicate that, following extensive societal debate about the acceptability of different applications of emerging enabling technologies, experts recognise those factors which lead to societal acceptance or rejection. This may provide further evidence that lay opinions regarding technology do not differ as much from those as experts as has been often assumed (also see Leviston et al., 2013).

Some determinants of societal acceptability differentiated experts and consumers. Consumers indicated that socio-ethical factors, such as equitable distribution of benefits associated with emerging technologies, represented an important determinant of acceptability. This was not considered relevant by the experts. In contrast, experts identified physical contact with nanomaterials, and the time to market introduction, as being important factors influencing societal response to nanotechnology. These factors were not identified by consumers as relevant. Thus the results do not confirm the assumption that experts base their opinions solely on technical assessments whereas the public base their opinions on perceptions, emotions and other societally relevant factors. However, experts may be influenced by their own concerns about risk assessments, which they translate into societal priorities. The current thesis gives indications this might be the case, for example, where experts raise the issue of societal concern about consumer contact with nanomaterials, which may be attributed to their knowledge about risk assessment and exposure research. So despite the expert's awareness of the importance of societal acceptance, and its foundation on social psychological factors such as risk perception, experts none-the-less focus more on the technical properties of nanotechnology when developing an implementation trajectory. Experts may judge this as more important than factors which are important to consumers and society regarding technological innovation, such as fairness of equity of distribution of benefits or ethical concerns.

The differences between expert and consumer views which have been identified lends further credence to the argument that it is important to incorporate concerns voiced by broader society (the general public or the potential consumers of the products of nanotechnology) into technology development and policy formulation regarding risk analysis and other innovation strategies for nanotechnology (and indeed other emerging technologies). Developing dialogue between technologists and the public as part of technology assessment will ensure that social and ethical issues are addressed early in the development of emerging technologies. The findings in this thesis underline the need to include analysis of societal concerns, ethical analysis and public engagement in nanotechnology development programmes (EuropeanCommission, 2004; Roco and Bainbridge, 2005). Such engagement may have resulted in the limited societal protests against nanotechnology to date. However, constant re-evaluation of "what the public think" is needed, as this is unlikely to be static but rather influenced by external events, including the order of entry of products into the marketplace. Upstream public engagement or public deliberation in the early stages of technology development and application may ensure even better embedding of the views of the public in the commercialisation trajectory and process of policy development, which might draw on both public engagement and larger more representative surveys (Kearnes and Wynne, 2007; Macnaghten et al., 2005).

Specific differences between experts and the public can be identified. The most obvious difference is that experts indicated that they perceived that consumers would not accept nanotechnology applied within the agri-food sector. This was not found to be the case with the consumers. One interpretation is that experts perceive the negative consumer reactions to GM foods (in particular in Europe) to represent the "normative" consumer response to emerging technologies applied to food production (see *inter alia* Frewer et al., 2011b, van Dijk et al. (in preperation)). Extrapolation from the case of GM foods may not reflect socio-political changes which have occurred subsequent to their introduction (for example, the enactment of increased regulation designed to promote consumer protection). In addition, changes may have been made in technology development trajectories such that applications with obvious consumer benefits are prioritised in terms of market entry. Furthermore, socio-economic environments may have changed (for example, lower prices may be more of a priority in a recession when consumers have lower disposable incomes). While the research presented here suggests that experts extrapolated from the GM case to nanotechnology development (in particular in the area of agrifood production), experts were not explicitly asked whether this was important in their deliberations, and further research may be warranted. Against this, the general public does not appear to refer to GM applied to food production when considering nanotechnology applied to the same area. Rather, different applications are likely to be accepted if perceived risks are low, and perceived (personal and /or societal) benefits are high. It is of course possible that public attitudes may change following the occurrence of a negative event (or an event *perceived* as negative) associated with nanotechnology. It should be noted that the research reported in this thesis assessed expert and consumer opinions at static points in time. The importance of different determinants may change over time, once nanotechnology applications become more prevalent within society or because of change in prevailing cultural and societal environments (Cobb, 2005; Schütz and Wiedemann, 2008). For example, media coverage may increase and depending on its content, influence public opinion (Ho et al., 2008; Nisbet et al., 2003; Nisbet and Lewenstein, 2002). This supports the arguments for longitudinal analysis of attitudes as external events change.

When asking both expert and lay participants which factors they think will determine successful societal introduction of nanotechnology using free elicitation techniques, benefits emerge as the most important for both groups (compare chapter 3 and 5 in table 7.1). If risk is introduced into the discussion, (i.e. the researcher imposes the concept into a survey), both experts and the public rated risk as the most important factor determining acceptance (compare chapter 4 and 6 in table 7.1). Thus introducing risk into the design of experimental materials appears to frame participant responses. In turn, once introduced, risk is weighed more heavily in decision-making. In addition, the literature review conducted in chapter 2 implied that knowledge and trust would be important determinants of public acceptance of novel technologies. However these 2 determinants did not emerge from the elicitation techniques applied in chapter 3 and 5. This may imply that trust is not as important a determinant of consumer attitudes to novel technologies, (as has been suggested in the existing literature), and has been introduced as an influential construct by the methodologies applied by researchers; or trust may be less relevant to nanotechnology specifically. Alternatively, the methods and approaches applied in this thesis may not have elicited the issue of trust as being important to participants. Similarly, consumer knowledge about science and technology has also been raised as one of the most important determinants of acceptance in the literature review conducted in chapter 2. However, knowledge was not spontaneously raised in elicitation studies included in this thesis by experts or consumers. In addition, in the research presented here, experts do not refer to the consumer "knowledge deficit" which they have, in the past, assumed leads to consumers rejecting technologies and its applications, and there was no suggestion that societal acceptance could be increased by increasing the scientific knowledge held by laypeople. Again, this implicitly suggests that experts are aware of the socio-cultural factors which shape social acceptance of technologies and their applications.

One conclusion of this research is that methodologies applied may influence identification of which factors influence consumer acceptance. Reliance on a single method may provide only a limited insight into participants' opinions, and therefore a combination of methods should be utilised and the results integrated. The differences between the literature review, the free elicitation studies and the surveys, and those between the public and experts suggest that policy recommendations in this area should be based on evidence derived from the triangulation of different methodological approaches to ensure the best information can be bought to bear on the policy issue under consideration.

Implications for the commercialisation of nanotechnology applications and products

Public and expert views on societal response to different applications of nanotechnology applications can be used to develop a "roadmap" for their commercialisation.

The results of the research presented in this thesis indicates that public opinion regarding different nanotechnology applications are generally *not* negative, a finding consistent with previous research (e.g. Fischer et al., 2012). In general, the public seems to be unconcerned about many applications of nanotechnology. The exception relates to those areas of application where societal concern already exists (for example, in the area of pesticides, Kinkela, 2005). It is important to note that these concerns are not necessarily associated with the use of nanotechnology as such but are rather linked to the area of its application. For example, in case of smart pesticides, people may be concerned about the use of pesticides in agriculture (Bruhn et al., 1991; Harris et al., 2001) rather than the use of *smart* pesticides specifically. Taken together, there is little evidence presented in this thesis which can be interpreted as indicating that the public have particularly negative attitudes towards nanotechnology at all.

7.3 Limitations and future research

One limitation of this thesis is that within the expert opinion studies (chapter 3 & 4), no distinction between stakeholder groups could be made due to the limited number of experts in each stakeholder group (i.e. NGO, media, industry, government and academia). Different expert groups may differ in their prioritisation of issues for policy agendas. For example, scientists lead in the development of enabling technologies, as well as their application and implementation. Industry has an interest in manufacturing and commercialising products developed using nanotechnology. Policymakers are responsible for developing and implementing policies regarding nanotechnology regulation, as well as promoting economic exploitation where appropriate. Non-governmental organisations raise issues for public debate and provide counterweight arguments to those produced by other stakeholders. The media plays an important role in information dissemination. It should be noted that, in the research reported in this thesis, experts from the academia and research institutes were somewhat overrepresented and experts from media and NGOs were underrepresented, which might have influenced the overall conclusions. Future research may extend the expert studies to include a broader range of stakeholders, and include a larger more representative sample of the stakeholder constituency.

The empirical studies examining consumer perceptions is that they were conducted in the UK, which may limit the generalisability of the findings to different cultures and contexts (chapter 5 & 6). Similar results from the Netherlands have been obtained (van Dijk et al., tion) but UK and the Netherlands are culturally similar, and so differences associated with larger cultural differentiation would not be identified through this comparison. The results obtained in one country may not be immediately applicable to populations in another(e.g. see, inter alia, Gaskell et al., 2005; Frewer et al., 2011b). It is important to examine whether cultural differences between countries and cultures exist, in particular with respect to attitudes in developing countries and emerging economies (see also chapter 2 of this thesis). In the near future, developments in nanotechnology and international trade will be potentially influenced by countries with emerging economies, particularly the BRIC countries (Palmberg et al., 2009). Expert and consumer opinions and attitudes need to be researched in these countries in order to provide a more comprehensive view of local factors relevant to policy development and technology exploitation.

Previous research has found evidence that people may use a number of heuristics such as the affect heuristic (Finucane et al., 2000; Slovic et al., 2007, 2002) where they base (for example) risk and benefit perceptions on general, unconscious, affective evaluations rather than on cognitive evaluations. In addition, factors such as past behaviour, habit and hedonic appreciation are recognised as important predictors of actual food choice behaviour (Köster, 2009) which are difficult to capture in the self-report techniques used in this thesis. However, as nanotechnology is in the initial stages of commercialisation, heuristics have not been established. As concrete examples of nanotechnology become available and can be assessed by consumers, future research should explore the unconscious determinants of consumer acceptance using experimental approaches, where behavioural measures may supplement self-report data. Lined to this is further understanding of how people process information for example, using elaborate or heuristic processing (Frewer and Fischer, 2010) which would directly inform communication policies.

The results of this research also form the basis for understanding factors influencing societal acceptance of emerging technologies such as synthetic biology where societal concerns about ethical acceptance, end-user and societal benefits, and the use of alternative technologies are also likely to arise. Some specific factors driving societal concern may also arise (as has been shown to be the case with nanotechnology in the research presented here). Analysis of expert and public views regarding societal preferences, priorities and concerns early in the development of these future technologies may facilitate their introduction and implementation.

7.4 Final conclusion

This thesis shows that for experts perceived risks, perceived benefits and concern about coming in contact with nanomaterials were the most important factors shaping societal response. In the case of consumers' perceived risks, benefits, need and socio-ethical concerns were the most prominent factors influencing consumer response. It is of interest to note that experts believed that public will reject nanotechnology applied to agriculture, which was not found to be the case when consumers were asked whether this will be the case. While some convergence between lay and expert opinions were identified regarding the factors which would influence societal acceptance of nanotechnology, some divergences were also identified. This indicates the need to incorporate societal and/or consumer concerns as well as expert assessment into the technology development process. At a time when innovations in nanotechnology are still developing and have not yet been commercialised, this thesis has provided insights into how different applications will be received by society, which in turn may provide information of relevance to developing 'effective risk-benefit communication of nanotechnology associated with specific applications.

Appendices

A.1 List of papers included in the analysis: In chapter 2

1. Adekunle, P. A., Omoba, R. O., & Tella, A. (2007). Attitudes of librarians in selected Nigerian universities toward the use of ICT. *Library Philosophy and Practice, 2007*(DEC.).
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A.2 Items used to measure factors influencing societal response to nanotechnology & certainty of expert response: In chapter 4

- How beneficial would an average member of the public in your country perceive *Application* on a 5 point scale, from 1 = extremely beneficial to 5 = not at all beneficial.
- How risky would an average member of the public in your country perceive *Application* on a 5 point scale, from 1 = extremely risky to 5 = not at all risky.
- How necessary would an average member of the public in your country perceive *Application* on a 5 point scale, from 1 = extremely necessary to 5 = not at all necessary.
- In your opinion how much an average member of the public in your country would worry over coming into contact with the nanomaterials used in *Application* on a 5 point scale, 1 = extremely worried about coming into contact to 5 = not at all worried about coming into contact.
- How long will an average member of the public in your country think it will take for the *Application* on a 5 point scale, 1 = already in the market; 2 = within 1 year in the market; 3 = between 2–3 years in the market; 4 = between 5–10 years in the market; 5 = will never reach the market.
- The word *Application* referred to the 5 agrifood applications of nanotechnology:

    1. targeted drug delivery
    2. smart pesticides developed using nanotechnology to enhance the effectiveness or delivery of pesticides
    3. encapsulation and delivery of nutrients in food (Nano-encapsulated food)
    4. food packaging using nanoparticles with antimicrobial properties to increase shelf life of food products
    5. development of efficient and cost effective water filtration process by using nanomaterials (water filtration)

A.3 List of construct–classes and total number of occurrences of each construct–class: In chapter 5

Construct class	Frequency	Construct class	Frequency
acceptable to society	4	less/non necessary	15.5
affect daily lives	2	less/not important	7
alternatives are available	7	makes lifestyle easy	5.5
beneficial for more people	7	more research needed	6
benefits for a subgroup of people in society	5	Necessary	19.5
benefits general	13	need more information	3
benefits have to be extreme to accept such an application	1	nice to have	8
cannot be misused/abused	1	no concern	2
Concern	3	no fear	2
could be misused/abused	3	no health benefits	2
daily use	6.5	no personal knowledge	8
desired by everyone	10	no personal benefits	1
direct benefits	3.5	not a good use of nanotechnology	3
do not affect daily lives	1.5	not acceptable to society	5
Doubts	11.5	not helpful	1
easy to understand	2	not used daily	2
environmental benefits	19.5	not/less desirable	7.5
environmental risks	0.5	novel application/added value	6.5
Fear	4.5	outside body	3.5
financial benefits	2	personal benefits	8

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Appendices

A.3. List of construct–classes and total number of occurrences of each construct–class: In chapter 5

Construct class	**Frequency**	**Construct class**	**Frequency**
Futuristic	2.5	personal use	2
good use of nanotechnology	4.5	privacy concern	6
health benefits	33	Real	4
health risks	2	regulations not required for commercialisation	1
Helpful	3.5	regulations required for commercialisation	1
Important	4	relevant for developing countries	4
indirect benefits	6	sense of control	3
inside body	3	take away jobs	3.5
issue of affordability	5	useful for general public	15
less/no benefits general	8.5	useful for subgroup of people	25

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Summary

Nanotechnology potentially has impacts across many different sectors, from agriculture and food production, to medicine, electronics, biomaterials and energy production to name but a few. Nanotechnology presents opportunities to develop new products and services, and may result in public health benefits, innovation and novel product development, and sustainable production. Rapid advances in the field of nanotechnology have raised both expectation and concern among different stakeholders (for example, academia, industry, government, NGOs, media and the public) regarding social, health and environmental consequences of applications of nanotechnology. The future of nanotechnology is surrounded with a considerable amount of uncertainty regarding the societal response to nanotechnology. Different socio-psychological factors are likely to influence societal responses to development and application of nanotechnologies. This dissertation identifies and describes several factors influencing societal response to nanotechnology by incorporating views from experts and the general public. For this purpose, three research approaches are explored: previous scientific work is reviewed to identify factors influencing societal response to new technologies, expert views on factors influencing societal response to nanotechnology are collected, and public views on nanotechnology are collected.

A review of the scientific literature on factors influencing public acceptance of 10 (controversial) technologies shows that there has been an increased interest and focus on public acceptance of technologies in academia (Chapter 2). The most frequently identified factors: risk, trust, perceived benefit, knowledge, individual differences and attitude were found to have been a focus of research in 60% of articles. Correspondence analysis suggests that some determinants (such as risk and benefit perceptions) have been used more extensively in association with some technologies compared to other determinants (such as perceived environmental impact and ethics).

Exploring expert stakeholder views on societal responses to nanotechnology at an early stage of technology development can helps in predicting how expert views are likely to influence the development, implementation and commercialisation trajectory of nanotechnology. In order to gain expert insights on societal responses to nanotechnology, structured interviews using repertory grid methodology were conducted using experts from North-West Europe to elicit their view on likely societal issues (chapter 3). According to interviewed experts, societal responses to different applications of nanotechnology will be (1) the extent to which applications are perceived to be beneficial, (2) useful and necessary, and (3) how "real" and (4) how physically close to the end-user these applications are perceived to be by the public. The results of this study were validated in an expert survey (Chapter 4) with an international group of experts drawn from Northern America, Europe, Australasia, India and Singapore to examine differences in expert opinion regarding societal acceptance of different applications of nanotechnology within different technological environments, consumer cultures and regulatory regimes. The results confirm the main factors influencing societal acceptance according to experts. The study also shows that experts across different regions have similar views on how these factors influence societal response to nanotechnology. In both the expert studies, experts were of the opinion that nanoencapsulated food will raise most societal issues and are least likely to be accepted by society. Other applications like targeted drug delivery and water filtration using nanotechnology were thought by experts to be more societally acceptable.

Societal response to nanotechnology by the general public is important for the success of any new technology as it will determine its subsequent development and commercialisation. Therefore public opinion regarding the applications and development of nanotechnology will be crucial in determining success or failure of nanotechnology. An exploratory study using an identical repertory grid protocol to that used in the expert analysis was used with to identify factors influencing societal acceptance of nanotechnology in the UK by the UK public, this time using consumers as study participants (Chapter 5). The results indicate that the general public differentiates nanotechnology applications based on the extent to which they perceive them to be (1) beneficial, (2) useful, necessary and important. These determinants are similar to those identified as important determinants by the experts. In addition, members of the general public also highlighted the importance of (3) social risks such as ethical concerns and equity issues regarding who will have access to the benefits of nanotechnology products. The availability of alternative technological approaches to product development may militate against acceptance of products developed from nanotechnology if these are perceived to be less risky. Food applications of nanotechnology are in general considered positively, which is at odds with both earlier studies with the public and the results of the expert studies presented in this thesis, where experts consider foods to be among the products of nanotechnology which will

be the most negatively perceived products. Consumer opinion about different applications of nanotechnology was further explored in a national consumer survey in the UK. Beyond asking public response to the factors identified in the consumer repertory grid, outcomes of the literature review and the expert studies were included to allow for a more comprehensive overview of public response (chapter 6). The results suggest that risk and benefit perceptions, as well as perceived need and fear, influence consumer response to agri-food applications of nanotechnology. In addition, the potential for misuse/abuse of nanotechnology, the availability of equally effective (and potentially less risky) technologies other than nanotechnology to achieve the same goals, the extent to which nanotechnology applications will be "oversold" in terms of the benefits they will potentially deliver, and accessibility to nano-products will also influence consumer opinion. Perceived risk and concerns about technological implementation emerged as the most important factors in determining successful introduction of nanotechnology. Perceived benefit was also considered important in terms of consumer acceptance of specific products.

Together, the chapters in this thesis contribute in extending the existing research on technology acceptance by identifying factors that are likely to influence societal acceptance or rejection of nanotechnology. Evidence was found that in open interview around nanotechnology products, the perceptions focussed more on benefits, while in surveys; risks were consistently labelled as more important compared to benefits. While some convergence between lay and expert opinions were identified regarding the factors which would influence societal acceptance of nanotechnology, some divergences were also identified. Their views did not appear to align with each other when discussing public acceptance of agri-food applications of nanotechnology. Having "learned" from the GM experience, experts believe that public would reject nanotechnology applied to agriculture, which was not found for consumers. Despite experts being able to identify many societal determinants of acceptance, the public raised additional issues, which stresses the importance to incorporate actual public concerns and not just expert assessment in the process of technology development. It is possible that public acceptance may change if a "high impact", negative event occurs in association with (agricultural) nanotechnology. It is recommended that a proactive communication programme about risks and benefits, which also addresses public concerns and priorities, is implemented.

Samenvatting

Nanotechnologie heeft de potentie om grote invloed te krijgen in veel verschillende industriële sectoren. Deze invloed kan zich bijvoorbeeld uitstrekken van landbouw en voedselproductie, tot medicijnen, elektronica, biomaterialen en energieproductie. Nanotechnologie creëert mogelijkheden voor de ontwikkeling van nieuwe producten en diensten, en kan daardoor voor volksgezondheidsvoordelen zorgen, innovatieve en nieuwe productontwikkeling stimuleren alsook duurzame productie. Door de snelle vooruitgang op het gebied van de nanotechnologie zijn er onder de verschillende belanghebbenden (zoals wetenschap, industrie, overheden, Ngo's, de media en het publiek) tegelijkertijd hoge verwachtingen gewekt en zorgen over sociale, gezondheids- en omgevingseffecten van nano-technologische toepassingen. De maatschappelijke reactie op nanotechnologie is nu nog onzeker, maar de toekomst van nanotechnologie is mede afhankelijk van deze reactie. Het is waarschijnlijk dat verschillende sociale en psychologische factoren de maatschappelijke reactie op de ontwikkeling en toepassing van nanotechnologie zullen beïnvloeden. Dit proefschrift identificeert en beschrijft verschillende van deze factoren door standpunten van experts en het publiek te integreren. Voor dit doel zijn drie onderzoeks-aanpakken gebruikt: een literatuuroverzicht wordt gegeven van eerder wetenschappelijk werk over de identificatie van factoren die van belang zijn voor maatschappelijke acceptatie van nieuwe technologieën. Daarna worden standpunten van experts aangaande factoren die de maatschappelijke reactie op nanotechnologie veroorzaken onderzocht en wordt de mening van het publiek over nanotechnologie onderzocht.

Een overzicht van de wetenschappelijke literatuur, naar factoren relevant voor de publieke acceptatie van 10 (controversiële) technologieën, laat zien dat er in de wetenschap een toegenomen belangstelling voor, en focus op de publieke acceptatie van technologieën is ontstaan (hoofdstuk 2). De meest voorkomende factoren zijn: risico, vertrouwen, waargenomen voordeel, kennis, individuele verschillen en attitudes. Deze factoren werden als onderwerp in 60% van alle artikelen gevonden. Uit een correspondentie analyse blijkt dat sommige voorspellers van acceptatie (zoals percepties van risico's en voordelen)

vaker gebruikt zijn in vergelijking tot andere voorspellers (zoals waargenomen milieueffect en ethische afwegingen); en dat sommige voorspellers vaker gebruikt zijn in relatie tot specifieke technologieën, dan voor andere technologieën.

Het in een vroeg stadium van technologieontwikkeling onderzoeken van de ideeën van expert belanghebbenden met betrekking tot de verwachte maatschappelijke reactie op nanotechnologie, kan helpen in het voorspellen van de invloed die deze experts hebben op de ontwikkeling, invoering en commercialisering van nanotechnologie. Aan de hand van de repertory grid methode zijn gestructureerde interviews gehouden met experts om inzichten te krijgen over wat experts denken dat de maatschappelijke reacties en de bijbehorende maatschappelijke kwesties op nanotechnologie zijn. De interviews zijn uitgevoerd onder experts uit Noordwest-Europa (hoofdstuk 3). Volgens de ondervraagde experts, zal maatschappelijke reactie op verschillende nanotechnologie toepassingen afhangen van (1) de mate van voordeel die van een toepassing wordt verwacht (2) hoe bruikbaar en noodzakelijk de toepassing wordt gezien (3) hoe realistisch een toepassing is en (4) hoe fysiek dicht bij de toepassing bij de eindgebruiker komt volgens het publiek. De uitkomsten van deze studie zijn gevalideerd in een vragenlijst onder experts (hoofdstuk 4). Een groep internationale experts uit Noord-Amerika, Europa, Australië en Nieuw-Zeeland, India en Singapore hebben deelgenomen aan de vragenlijst. Hiermee werden de verschillen in expert mening over maatschappelijke acceptatie van verschillende toepassingen van nanotechnologie in verschillende technologische contexten, consumentenculturen en wetgevingsregimes onderzocht. De resultaten bevestigen de belangrijkste factoren die volgens experts maatschappelijke acceptatie beïnvloeden. De studie laat ook zien dat de experts in de verschillende regio's vergelijkbare ideeën hebben over hoe deze factoren maatschappelijke reactie op nanotechnologie beïnvloeden. In beide expertstudies waren de deelnemers van mening dat nanoencapsulatie in voeding de meeste maatschappelijke ophef zou veroorzaken en het minst waarschijnlijk maatschappelijk geaccepteerd zouden worden. Andere toepassingen zoals gerichte medicijntoediening en waterfiltering met nanotechnologie werden als meer maatschappelijk acceptabel gezien door experts.

De reactie van het algemene publiek op een nieuwe technologie is belangrijk voor het succes van deze technologie, aangezien die reactie bepalend zal zijn voor daaropvolgende ontwikkeling en commercialisatie van de technologie. Om die reden zal de publieke mening over toepassing en ontwikkeling van nanotechnologie cruciaal zijn om succes of falen van nanotechnologie te bepalen. Een exploratieve studie is gehouden onder het publiek in het Verenigd-Koninkrijk. Daarvoor is een identiek repertory grid protocol gebruikt, als datgene gebruikt om onder experts de factoren die maatschappelijke acceptatie van nanotechnologie bepalen vast te stellen. Dit keer werd het onderzoek met consumenten als deelnemers uitgevoerd (hoofdstuk 5). De uitkomsten geven aan dat het algemene publiek nanotechnologie toepassingen onderscheidend beoordeeld naar mate dat ze deze (1) voordelig (2) bruikbaar, nodig en belangrijk vinden. Deze factoren zijn vergelijkbaar met de factoren die door experts als belangrijk werden geïdentificeerd. Bovendien werd door het algemene publiek ook de nadruk gelegd op het belang van (3) sociale risico's, zoals risico's die voortkomen uit ethische zorgen en zaken met betrekking tot gelijkheid over wie toegang zal hebben tot de voordelen van de nanotechnologie producten. Wanneer technologische benaderingen anders dan nanotechnologie, die als minder risicovol dan nanotechnologie gezien worden, beschikbaar komen voor kan dit voor weerstand zorgen in de acceptatie van producten ontwikkeld met nanotechnologie. Over het algemeen werden voedingstoepassingen van nanotechnologie positief beoordeeld, wat ingaat tegen zowel eerdere studies onder het publiek als de expertstudies in dit proefschrift, waarin experts voeding beschouwen als de productcategorie die het meest negatief beoordeeld zal worden door consumenten. Consumentenmeningen over verschillende toepassingen van nanotechnologie zijn vervolgens verder onderzocht in een landelijk vragenlijstonderzoek in het Verenigd-Koninkrijk. Naast het uitvragen van de publieke reactie op de factoren uit de repertory grid, werden ook de uitkomsten van het literatuuronderzoek en de expertstudie in de vragenlijst ingepast om een meer volledig overzicht van publieke reacties te krijgen (hoofdstuk 6). De resultaten geven aan dat risico- en voordeelpercepties, maar ook ervaren noodzaak en angst, consumentenreactie op agrifood toepassingen van nanotechnologie beïnvloeden. Bovendien wordt de consumentenopinie beïnvloed door de kans op misbruik of verkeerd gebruik van nanotechnologie, de beschikbaarheid van net zo effectieve (en mogelijk minder riskante) technologieën anders dan nanotechnologie, de mate waarin nanotechnologie toepassingen overdreven voordelig worden voorgesteld in relatie tot de reëel mogelijke voordelen, en de toegankelijkheid van nano-producten voor het brede publiek. De meest belangrijke bepalende factoren voor succesvolle introductie van nanotechnologie bleken waargenomen risico en zorgen over de technologische uitvoering te zijn. Waargenomen voordeel werd ook als belangrijk gezien, vooral in relatie tot consumentenacceptatie van specifieke producten.

Bij elkaar dragen de hoofdstukken in dit proefschrift bij aan het bestaande onderzoek over technologie acceptatie door de identificatie van factoren die waarschijnlijk maatschappelijke acceptatie of afwijzing van nanotechnologie beïnvloeden. Aanwijzingen zijn gevonden dat in open interviews over nanotechnologie producten de meningen meer op basis van voordelen werden gevormd, terwijl in vragenlijsten risico's consequent als belangrijker werden aangemerkt. Inzicht in de standpunten van experts en het algemene publiek laten zien dat experts en consumenten het eens zijn over de verschillende factoren die de maatschappelijke reactie ten aanzien van nanotechnologie beïnvloeden. Er werden echter ook een aantal verschillen gevonden. Standpunten van experts en leken bleken van elkaar af te wijken wanneer het ging over de publieke acceptatie van landbouw- en voedseltoepassingen van nanotechnologie. Met de lessen van de introductie van genetische modificatie in het achterhoofd geloven experts dat het publiek nanotechnologie in de landbouw zal afwijzen. Deze mening werd echter niet bij consumenten gevonden. Ondanks dat experts vele maatschappelijke voorspellers van acceptatie konden noemen, werden door het publiek aanvullende onderwerpen opgebracht. Dit onderstreept het belang van het gebruiken van daadwerkelijk publieke bezorgdheid in het proces van technologie ontwikkeling, en niet alleen de inschattingen van experts over die bezorgdheid. Het is mogelijk dat publiek acceptatie alsnog veranderd als er invloedrijke negatieve situaties optreden gerelateerd aan (landbouw gerichte) nanotechnologie. Het wordt daarom aanbevolen om een proactief communicatieprogramma over risico's en voordelen in te voeren dat ook publieke zorgen en prioriteiten in ogenschouw neemt.

List of publications

1. Gupta, N., Fischer, A.R.H, & Frewer, L.J. (2012). Socio psychological determinants of public acceptance of technologies: a review. *Public Understanding of Science*, 21(7), 782 - 795. doi: 10.1177/0963662510392485

2. Gupta, N., Fischer, A.R.H., van der Lans, I., & Frewer, L.J. (2012). Factors influencing societal response of nanotechnology: an expert stakeholder analysis. *Journal of Nanoparticle Research*, 14(5), 1-15. doi: 10.1007/s11051-012-0857-x

3. Gupta, N., Fischer, A. R. H, George, S., & Frewer, L. J. (2013). Expert views on societal responses to different applications of nanotechnology: A comparative analysis of experts in countries with different economic and regulatory environments. *Journal of Nanoparticle Research*,15(8), 1-15. doi: 10.1007/s11051-013-1838-4

About the author

Nidhi Gupta was born in New Delhi, India on June 12, 1982. She graduated in Botany, Honours from Delhi University, India with first division in 2003. In the same year she joined Master of Science program in Natural Resources, from TERI University, Delhi. In 2008, she started her PhD at the Marketing and Consumer Behaviour group of Wageningen University. The results of this research are presented in this thesis. In 2011, Nidhi visited Australian Centre of Excellence for Risk Analysis, Melbourne for three weeks to learn expert elicitation tool and to present a seminar on her research work. She was also invited to present a seminar at the Institute of Environmental Science and Research Ltd. (ESR), New Zealand in 2011. One of her publications on expert opinion on nanotechnology was picked as research highlight in Nature Nanotechnology.

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Nidhi

Nidhi Gupta
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the course	Department/Institute	Year	ECTS*
I. General part			
Techniques for Writing and Presenting a Scientific Paper	Wageningen Graduate School	2010	1.2
Science, the press and the general public: communication and interaction	Wageningen Graduate School	2009	1
WIAS Advanced Statistics course Design of Experiments	WIAS Course	2011	1
II. Mansholt-specific part			
Mansholt Introduction course	Mansholt Graduate School	2008	1.5
Seminar: Nanotechnology & Consumer Behaviour	ACERA, Melbourne	2011	1
'Factors Shaping Societal response of nanotechnology: An expert stakeholder analysis'	WASS PhD-day	2012	1
'Factors Shaping Societal Acceptance of New Technologies: Insights from the Literature'	4S Annual meeting, Tokyo University, Tokyo	2010	1
'Determinants influencing societal uptake of nanotechnology: An expert stakeholder analysis'	Budapest	2011	1
PhD Council	Mansholt Graduate School	2008-2010	2.5
Atlas.ti Program practical	Mansholt Graduate School	2010	0.5
III. Discipline-specific part			
Food Risk Analysis	Mansholt Graduate School	2009	3
Quantitative Data Analysis: Multivariate Techniques (YRM 60306)	Wageningen University	2009	6
Social Psychology, the individual and the social world	Cornell University	2009	5
Expert Elicitation tool	ACERA, Melbourne University	2011	3
'Will consumers & society accept nanotechnology in future foods?'	ESR, New Zealand	2011	1
Marketing Series	MCB Group, Wageningen University	2009	1
Total (minimum 30 ECTS)			**30.5**

*One ECTS on average is equivalent to 28 hours of course work

Abbreviations
WIAS stands for Wageningen Institute of Animal Sciences
ACERA stands for Australian Centre of Excellence for Risk Analysis
ESR stands for The Institute of Environmental Science and Research Ltd
MCB stands for Marketing and Consumer Behaviour Group

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