An Exploration of Irish Consumer Acceptance of Nanotechnology Applications in Food

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Abstract

Nanotechnology has come to the attention of food stakeholders in recent years. It offers many potential benefits to food companies and consumers, for example the ability to produce healthier food without compromising taste, but it has also generated much debate, in particular about potential unknown risks associated with food applications of nanotechnology. This research provides some insights into Irish consumer acceptance of food related applications of nanotechnology and details the determining factors framing consumers' attitudes. Key issues investigated include consumers' awareness of and attitudes towards nanotechnology, the subjective values (including perceived risk-benefit trade-offs) that frame these attitudes and the influence of new information on consumers' attitudes and acceptance. An innovative methodology was applied involving observations of a one-to-one deliberative discourse between a food scientist specialising in nanotechnology research and consumers. The aim of this research was to understand the evolving perspectives of the individual consumer as information was presented to them. During the discourse, the scientist presented a number of pre-defined hypothetical scenarios, illustrating benefits and risks of different food applications of nanotechnology in an effort to establish 'tipping points' in consumer acceptance. In-depth pre and post-discourse interviews were also completed with participants (n = 7; 21 observations in total) to determine the perceived influence of the discourse on consumers' acceptance and the factors contributing to any attitudinal change. Thematic analysis was undertaken with the support of the software package NVivo8. A brief questionnaire was completed by participating consumers to support some of the qualitative findings. While participants were unfamiliar with the concept of using nanotechnology in food production, in general, new information appeared to positively impact their attitudes towards food applications of nanotechnology. This increased their perceived likelihood of purchasing foods that incorporated nanotechnology applications during processing or packaging. Consumers were more accepting of the different applications presented if they perceived the associated personal and societal benefits to outweigh potential risks. However, consumers were not homogenous in their perceptions of the applications. Product characteristics (e.g. perceived naturalness), subjective values including the perceived individual relevance of such 'nano food' products, individual risk assessments, trust in stakeholders and personal control, general risk sensitivity and attitudes towards technology, familial relevance of such applications, and societal and environmental factors framed consumers' attitudes towards the nanotechnology applications presented. Furthermore, acceptance was conditional on potential risks being adequately addressed before 'nano foods' reach the market. How risks are 'adequately addressed' is a key question emerging from this research. As a small number of consumers participated in this study, the findings presented are by no means representative of Irish consumers. However, the diversity of factors framing participants' attitudes and acceptance indicates the relevance of the issues raised at a broader level.

Key Words: *Novel food technologies, nanotechnology, consumer acceptance, risk perceptions, risk communication, deliberative discourse*

1 Introduction

Novel food technologies (NFTs) are scientific and technological developments that may be adopted by industry to enhance the way food is produced or processed. Such developments are fundamental to the future competitiveness of the food industry. These technologies may or may not result in differentiated products for consumers. Nonetheless, from a marketing perspective, they can provide the food industry with opportunities to satisfy consumers' diverse and increasingly conflicting demands from food products, including demands for convenient, tasty, healthy and affordable food products.

McCrea (2005) notes that investment in NFTs will not yield desired returns unless accepted by consumers. However, as is clearly evident from public rejection of genetically modified foods, acceptance cannot be assumed (Shaw, 2002) and lack of acceptance can result in significant costs. Public (consumer) wariness towards NFTs is sometimes explained by their vision of the future roles and values of NFTs differing from other stakeholders (Gaskell *et al.*, 2006). In particular, the framing of risk and the evaluative criteria used by the public differ to those used by scientists. Shepherd (2008) suggests that the public may have concerns about food related risks which are outside the risk framings imposed by scientists and regulators. These risk framings need to be considered if effective communication to the public on the topic of NFTs is to be achieved. A greater appreciation of these framings could enhance communication and interaction between stakeholders, which should in turn facilitate informed consumers' decision making about NFTs and may even result in greater consumer acceptance (House of Lords, 2010). One such technology - nanotechnology - has come to the attention of food stakeholders in recent years as it offers many potential benefits to food companies and consumers, for example the ability to produce healthier food without compromising taste (Kuzma & VerHage 2006). However nanotechnology has also generated much debate, in particular about potential unknown risks associated with its applications to food (Siegrist *et al.,* 2008).

1.1 Applications of Nanotechnology in Food Processing and Packaging

The prefix 'nano' is derived from the Greek noun 'nanos' meaning dwarf or small (Cross *et al.,* 2010). Thus nano is concerned with a size or measurement and in the context of science and technology; a nanometre refers to one-billionth of a metre. The Royal Society & Royal Academy of Engineering define nanotechnology as "*the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometre scale"* (2004:79)[1]. Although many nanoparticles occur naturally in foods, this paper focuses on nanoparticles that have been purposely manipulated or engineered for food applications. The concept of manipulating matter at a very small scale is not new (Feynman, 1959), with sectors such as computers, pharmaceuticals and cosmetics doing so for some time (FAO/WHO, 2009). In recent years, significant 'nano' research has been undertaken to enhance the taste, colour, texture, health characteristics and consistency of food products. Foods, for example, can be rendered healthier by reducing their fat and salt content without compromising taste, and increasing the bioavailability of certain nutrients (Food Safety Authority of Ireland, 2009). Furthermore, engineered nanomaterials (ENMs) and nanosensors may be used in food

[1] Significant debate is ongoing in the scientific community regarding definitions of nanotechnology. Canady (2010) provides an overview of related issues.

packaging to create 'smart packaging' that increases food safety and indicates food spoilage (FAO/WHO, 2009). However, in spite of the significant research taking place, there are a limited number of 'nano foods'[2] on the market at present (Siegrist *et al.,* 2008).[3]

The properties of materials at the nanoscale can be very different from conventional materials (Oberdörster *et al.,* 2005). Consequently, research has concentrated on understanding these properties and how innovative food products can be developed from applications of nanotechnology. While such applications offer many potential benefits (Renn & Roco 2006), the unknown potential risks of nano foods have generated significant debate (House of Lords, 2010; Chaudhry *et al.,* 2008). Interested parties have expressed growing concerns that the impacts of certain nanoparticles on the health of humans, animals and the environment are not fully understood (FAO/WHO, 2009; Royal Society & Royal Academy of Engineering, 2004). For example, there are concerns that engineered nanoparticles (which could potentially be used in food packaging) may interfere with the growth of beneficial bacteria in the environment (Kuzma & VerHage 2006). Furthermore, a number of studies suggest that these nanoparticles could potentially pass the blood-brain barrier, possibly impacting the central nervous system (Oberdörster *et al.,* 2005).

The lack of definitive scientific evidence regarding unknown long term risks associated with engineered nanomaterials has resulted in some stakeholders, notably regulatory authorities and also some civil society organisations, arguing that the precautionary principle should be adopted (Stampfli *et al.,* 2010; Oberdörster *et al.,* 2005). For example, organisations such as Friends of the Earth have called for a halt in the commercial release of foods linked to nanotechnology until specific laws regarding its application are enacted and public engagement has occurred (Friends of the Earth, 2008). In light of these developments, discussions and reviews are underway at an EU level about regulatory, detection, classification and labelling issues surrounding the use of nanotechnology in food production and packaging (Mantovani *et al.,* 2010; European Food Safety Authority, 2009). The European Food Safety Authority recently launched a public consultation on its draft guidance document for engineered nanomaterial applications in food and feed (European Food Safety Authority, 2011).

Clearly, the risk and benefits of nano foods need to be communicated to consumers in a transparent and timely manner. Siegrist *et al.* (2007a, 2008) argue that the importance of identifying and incorporating the public's views of nano foods at an early stage of technological and product development should not be underestimated. This view is echoed by Chaudhry *et al.* (2008:256) who state that *"public confidence, trust and acceptance are likely to be the key factors determining the success or failure of nanotechnology applications for the food sector".* Siegrist (2010) believes that consumer perspectives can directly and indirectly impact the progress of new technologies. A direct effect might be outright rejection whereas indirect effects could include the imposition of stricter regulations by governmental agencies, potentially leading to higher production costs. Kuzma & VerHage (2006) go so far as to suggest that if public views are not taken into account, the food industry may witness consumers searching the supermarket shelves for products claiming to be 'nano-free'.

[2] For the purposes of this paper, 'nano foods' refers to food products and food packaging produced using applications of nanotechnology.

[3] The Project on Emerging Nanotechnologies (2010) compiled a database of all commercial products claiming to use nanotechnology which includes a food and drinks category (http://www.nanotechproject.org/).

1.2 Determinants of Consumer Acceptance

Understanding and knowledge can be influential in shaping the public's perception of NFTs, including nanotechnology (Cardello *et al.,* 2007; Macoubrie, 2006). However, a prerequisite to knowledge is awareness and recent studies suggest that there are low levels of public awareness of nanotechnology and its applications across different sectors (e.g. Macoubrie, 2006; Kahan *et al.,* 2007; Lee *et al*., 2005). That said, awareness levels differ across countries and applications. While a survey completed by the Hart Research Associates (2009) suggests that almost $^{2}/_{3}$ of US citizens may have heard of nanotechnology, another survey (International Food Information Council, 2010) indicates that a similar proportion of US citizens are unaware of food related applications of this technology. Awareness levels within Europe are even lower. Gaskell *et al.,* (2010) research findings suggest that just less that ½ of EU-27 citizens and $^{1}/_{3}$ of Irish citizens were aware of nanotechnology[4]. Interestingly, this study found that awareness generally resulted in a more positive view regarding the safety of nanotechnology. However, the latest Eurobarometer (2010) survey on this topic draws particular attention to food applications of nanotechnology and the findings suggest that almost ½ of EU-27 (37% of Irish) citizens may be 'worried' about nanoparticles being found in their food. Gaskell *et al.,* (2010) findings also indicate that a significant minority (40%) of EU-27 citizens are likely to be unsure how they felt about applications of nanotechnology. This clearly illustrates the need for public engagement as attitudes towards nanotechnology are not yet strongly formed (Lee *et al.,* 2005). Siegrist (2008) concludes that a lack of awareness results in consumers being unable to make informed assessments of the potential benefits and risks associated with nanotechnology, including food related applications. While public awareness of nanotechnology is currently low, more information is becoming available in mass media, including newspapers and the internet about how this technology may be used in food production and consequently views and attitudes are forming that will influence consumer acceptance (Dudo *et al.,* 2011).

Multiple factors influence consumers' formation of attitudes and ultimately their acceptance or rejection of NFTs (Siegrist, 2008). In particular, consumers often use heuristics (simple rules either intuitive or learned) when forming views and making decisions in an uncertain world (Slovic, 1987). Commonly cited heuristics include trust and perceived control over exposure to a potential risk. Trust is an important heuristic, particularly in situations where individuals' knowledge about a technology is lacking (Siegrist & Cvetkovich, 2000), and there is substantial evidence that trust in the food industry influences consumers' attitudes and therefore may influence future market success of nano foods (Siegrist *et al.* 2007a, b, 2008; Yawson & Kuzma, 2010). However, low levels of public trust in both the food industry and government's ability to effectively manage risks associated with nanotechnology have been observed in the US (Macoubrie, 2005, 2006). Within Europe, Siegrist *et al.,* (2007a, b) found that trust in the food industry and government agencies influences public perceptions of nano foods. In the context of control, individuals' belief in their ability to control exposure to a technology can impact their acceptance (Henson, 1995). In particular, perceived personal control influences risk and benefit perceptions of nanotechnology and consequently may affect acceptance (Renn & Roco 2006; Siegrist *et al.*, 2008). Labelling can increase perceptions of personal control in terms of choosing to consume foods produced using NFTs (Costa-Font *et al.,* 2008). Furthermore, Siegrist *et al.* (2007a) found that nano foods may be more acceptable to consumers if perceived tangible benefits are associated with such products. It is generally agreed that in the absence of

[4] This survey focused on the use of nanotechnology in cosmetics, sun creams and household cleaning fluids.

perceived benefits, consumers are unlikely to react positively towards nano foods (FAO/WHO, 2009).

As noted, risk assessments also contribute to attitude formation. Thus, it is not surprising that some researchers have focused their attention on the factors influencing the formation of risk perceptions. Kahan *et al.* (2007) and Siegrist *et al.* (2007a) found that nanotechnology risk perceptions can be affect driven. Furthermore, uncertainty about potential unknown risks contributes to consumers' formation of risk perception (Yeung & Morris, 2001). Consumers' attitudes toward and acceptance of NFTs are also influenced by their general attitudes and values, including their attitudes towards technology and nature (Grunert *et al.,* 2003). In particular, Kahan *et al.* (2007) found that individuals' values influence reactions (both positively and negatively) to information about the benefits and risks of nanotechnology applications. Furthermore, individuals' initial attitudes can significantly impact acceptance. Slovic (1987) highlights that initial opposition to a technology will not necessarily evaporate in the presence of scientific evidence supporting the technology, as individuals' opposing views may be resistant to change and therefore influence their interpretation of the information presented. Attitudes towards NFTs may also be influenced by concepts and images that consumers associate with the technology (Siegrist, 2008). For example the use of nanotechnology in ammunition production could potentially have a negative impact on the public's general image of nanotechnology and its applications in other sectors (Siegrist *et al.,* 2007b).

Cultural and social norms influence consumers' food consumption choices and therefore, may also influence acceptance of NFTs (Siegrist, 2008; Ronteltap *et al.,* 2007). Kahan *et al.* (2009:87) found that public attitudes towards nanotechnology are likely to be framed by *"psychological dynamics associated with cultural cognition".* This reflects the tendency of individuals to base their beliefs about the risks and benefits of an activity on their cultural appraisals of the activity (DiMaggio, 1997). As previously mentioned, when consumers do not possess knowledge about the risks and benefits associated with NFTs, they must rely on trust in stakeholders and this trust judgement is influenced by cultural and social norms (Siegrist, 2008). Mass media has also been shown to influence consumer acceptance of NFTs, particularly gene technology, potentially distorting scientific information by possibly over-dramatising it or presenting information in an unbalanced manner (Görke & Ruhrmann, 2003). Consumers' attitudes towards the environment have also been found to influence acceptance of NFTs, specifically gene technology (Siegrist, 1998). In addition, Stampfli *et al.* (2010) and Lee *et al.,* (2005) found that attitudes towards science and technology, in general, influence assessments of nanotechnology, including food applications.

Product characteristics including perceived taste, quality, naturalness and price also appear to influence consumer acceptance (Siegrist, 2008). Natural food products are often viewed as healthier, more environmentally friendly and appealing to the senses than processed alternatives (Rozin, 2005). Stampfli *et al.* (2010) and Siegrist *et al.* (2008) found that a greater preference for healthy and natural foods increased perceived risks and decreased perceived benefits associated with nano foods. Consumer acceptance may also depend on the specific food application of nanotechnology (Siegrist *et al.,* 2007b). For example, several studies undertaken in Switzerland on perceptions of food applications of nanotechnology found that nano packaging (nano-outside) is perceived as being less problematic, more beneficial and therefore, more acceptable than nano foods (nano-inside) (Siegrist *et al.,* 2007a, 2008; Stampfli *et al.,* 2010).

In summary, consumer acceptance of NFTs, including nanotechnology, is potentially influenced by a multitude of factors including consumers' perceptions of the risks and benefits associated with the technology, heuristics (including perceived control and trust in stakeholders), personal values and general attitudes, including attitudes towards technology and the environment and product characteristics including perceived quality, naturalness and price (Siegrist, 2008).

2 Aim of the study

This research provides some insights into Irish consumer acceptance of food applications of nanotechnology and details the determining factors framing consumers' attitudes. Consumers' awareness and attitudes towards nanotechnology, the subjective values that frame these attitudes, the influence of new information (and engagement mechanisms) on acceptance and the evolution of consumer attitudes are explored. This research will also suggest some suitable messages and approaches for industry and institutions involved in food risk communications to provide consumers with information about nano foods to aid their evaluations of nanotechnology.

The following research questions are addressed within this paper:

- How do consumers' perceptions (including attitudes and awareness) of the risks and benefits, and risk-benefit trade-offs, of food applications of nanotechnology impact on their acceptance of this technology and what are the 'tipping points' for acceptance[5]?
- What subjective values frame and re-frame consumers' attitudes and influence their acceptance/rejection of different food applications of nanotechnology?
- How does new information and consumer engagement with a scientist researching nanotechnology impact on consumers' framing and ultimately acceptance/rejection of nanotechnology?

Qualitative studies that illustrate "*the texture of public concern and the directions laypeople are keen for nanotechnology to take"* are still lacking (Von Schomberg & Davies, 2010:16). Brook Lyndhurst (2009:54) forcefully reiterates this point:

> *"There is a lack of good qualitative work examining the links between underlying values, expressed attitudes and actual behaviours in relation to novel food technologies and yet an understanding of how these three elements interact is absolutely necessary if one is to gain a full understanding of public perceptions."*

This qualitative research which examines the links between consumers' subjective values and expressed attitudes towards nano foods will add to the body of evidence within this area.

3 Methodology

"While every citizen might be regarded as a stakeholder in science for normative reasons, it does not imply that he or she should actually be asked, or have the right, to participate in the workings of science (…). What is important is to experiment with ways of interaction, and evaluate where they might lead" (European Commission, 2009:17).

[5] In the case of this research, a 'tipping point' refers to additional information that causes a shift (temporary or permanent) in consumer acceptance of food applications (specific or general) of nanotechnology.

To appreciate the significance of the different factors that frame consumers' attitudes towards nano foods, a research approach that allowed for the unfolding of participants' perspectives was applied. Of particular interest was to ascertain how flexible consumers were in their attitudes towards nano foods and how they framed and re-framed their attitudes as additional information was presented to them. Thus, a novel research methodology was applied involving observation of a one-to-one deliberative discourse (conversation) between a food scientist specialising in nanotechnology research and seven consumers, selected from the general public, about food related applications of nanotechnology. This approach provided depth rather than breath in terms of examining consumers' attitudes.

In recent years, there has been a conscious effort to involve the lay public in discussions about science and technology and to understand and appreciate their perspectives on these technologies, including nanotechnology (see Von Schomberg & Davies, 2010 and Bostrom & Lőfstedt, 2010 for an overview of various nanotechnology public engagement initiatives at the national and European level). However, methods of engagement used to date, such as citizen juries and consensus conferences, have predominately focused on achieving a consensus among a group of participants (Powell *et al.,* 2008). In contrast, the aim of this research was to understand the evolving perspectives of the individual consumer as new information about food related applications of nanotechnology was presented to them.

3.1 Recruitment of Participants

The scientist was selected to participate in this research based on his expertise in food related nanotechnology research and his availability to engage with others. The seven participating consumers were recruited based on pre-defined inclusion/exclusion criteria presented in a screening questionnaire. Given the novelty and exploratory nature of this methodological approach, a sample size of seven consumers was used. Consumers were only recruited to participate in the discourse if they:

- had not participated in a survey/focus group in the last six months,
- were not employed within the food sector,
- were directly involved in the food purchase decisions of their household (as these consumers can influence the food consumption decisions of the rest of the household),
- scored highly on a measure of confidence in interacting with others (as it was important to recruit consumers that were comfortable and confident in interacting with the scientist on a one-to-one basis)[6], and
- were not scientists by profession or training.

Consumers were also asked a variety of questions about their levels of subjective knowledge and concern about how food is produced and processed, to ensure a variety of perspectives among the recruited consumers. Finally, recruited consumers were dispersed across predefined gender, age and family status categories and socio-economic backgrounds. Although participants were recruited primarily based on their role as consumers; their attitudes as citizens were also addressed during the discourse. Consumers were given a monetary incentive (€50 payment) to participate in this research and were informed about this incentive at the recruitment stage.

[6] Questions posed were adapted from a scales developed by Day and Hamblin (1964).

In addition to the deliberative discourse, this qualitative investigation comprised in-depth interviews with participants before and after the discourse. Overall, this multi-method approach involves three interactions for each participant (consumer and scientist): a pre and post-discourse interview with the researcher and the discourse between the consumer and scientist[7].

3.2 Pre-Discourse Interviews

In-depth pre-discourse interviews were conducted by the researcher with the scientist to elicit his expert opinion on the benefits and risks associated with food applications of nanotechnology, which were then incorporated into the hypothetical scenarios presented to consumers during the discourse. While the pre-discourse interview with the scientist sought to illicit information, it also involved an element of 'training' to help support him in leading the deliberative discourse. As part of this training, the scientist was provided with a detailed 'discourse guide' to help navigate him through the discourse. The guide was designed to ensure consistency (i.e. a similar structure and context) across the discourses to allow for comparative analysis. The steps in the guide were designed to be sequential in nature, but the specific content of each step varied, depending on consumers' responses. The guide reiterated that the conversation with the consumer should be a two-way process with both parties initiating discussion, posing questions and reacting to the viewpoints expressed by the other party. Furthermore, the guide provided the scientist with prompt questions that he could pose to the consumer if necessary (i.e. if they were hesitant to 'open up' and express their reactions to the information presented). The guide also advised the scientist to stress he was not advocating nanotechnology, to ensure that consumers felt comfortable expressing their opinions, both positive and negative, during the discourse.

Prior to the discourse, the consumers participated in a brief interview with the researcher to establish their knowledge and attitudes towards the use of nanotechnology in food production. As public awareness of nanotechnology appears to be generally low (e.g. Macoubrie, 2006; Kahan *et al.,* 2007), following this interview the consumers were given a summary sheet about nanotechnology to read in advance of participating in the discourse. Consumers were not informed that they would be discussing nanotechnology in advance of this interview to control for proactive information searching. The summary sheet included some base-line factual (neutral) information on nanotechnology (Appendix 1)[8]. Perceived benefits and risks of nanotechnology were omitted so as not to influence consumers' attitudes towards nanotechnology prior to the discourse. Distributing the summary sheet ensured that each consumer had a minimum standard level of information and basic awareness of nanotechnology prior to the discourse and therefore could engage in the discourse with more confidence. During the discourse, the scientist was able to clarify and build on the information in the summary sheet. Therefore, it was a valuable reference document and departure point that formed the foundations of the discourse discussion.

[7] As the focus of this paper is on consumers' attitudes, the findings of the post-discourse interview with the scientist are not presented within this paper.

[8] The summary sheet was piloted on a range of individuals from different socio-demographic backgrounds to ensure clarity and comprehension. It was also circulated to the participating scientist for his review and comment.

3.3 The Deliberative Discourse

The researcher observed the deliberative discourse which commenced with the scientist explaining nanotechnology and its (potential) applications to food production and packaging to the consumer using lay terminology[9]. The scientist then briefly illustrated how nanotechnology could be used in food production. As part of this two-way interaction, the consumer had the opportunity to question the scientist throughout the discourse on any aspect of nanotechnology which he/she had concerns or was unclear about. Two nanotechnology pilot discourses were completed which confirmed that the proposed format and structure of the deliberative discourse were appropriate. The findings of the pilot discourses are presented within this paper, as part of the seven discourses analysed in total. Each hour-long discourse was audio recorded. Furthermore, video recording captured participants' non-verbal cues during the discourse that would not have been evident through audio recording alone (Uhrenfeldt *et al.*, 2007). As noted by Lomax & Casey (1998); Paterson *et al.* (2003) and Lotzkar & Bottorff (2001) a detailed review of these cues provided additional insights into the dynamics of the interactions between participants and their attitudes towards the issues discussed.

Several authors have commented how studies of public's attitudes towards nanotechnology, like earlier studies on attitudes towards GM foods, often examine consumers' attitudes towards the use of nanotechnology in food production in a general sense and do not examine their attitudes towards specific food applications, which may, in fact, vary considerably (e.g. Cook & Fairweather, 2007; Siegrist *et al.,* 2007a). During the discourse, the scientist presented a number of pre-defined hypothetical scenarios of specific applications of nanotechnology across food production, processing and packaging in an effort to establish 'tipping points' in consumer acceptance[10]. While the products and applications presented in the scenarios are hypothetical, the scenarios address topical issues within the area of food related nanotechnology research[11]. Developing the scenarios in advance ensured consistency in the information the scientist presented to the consumers, which facilitated comparative analysis of their reactions. These scenarios illustrated hypothetical benefits and risks (from a consumer, societal, environmental and industry perspective) of different applications of nanotechnology.

- Scenario 1: Food processing (removing unhealthy ingredients without compromising taste),
- Scenario 2: Food processing (adding healthy ingredients without compromising taste),
- Scenario 3: Food packaging (to increase shelf-life/indicate food spoilage etc.), and
- Scenario 4: Food production (nanocoatings on machinery).

Appendix 2 outlines the scenarios presented to consumers in detail. These scenarios built upon each other as part of an iterative process (i.e. starting with a straight-forward defined benefit of a specific nanotechnology application, building upon this scenario adding additional benefits, followed by known and unknown risks). Consumers were asked predefined questions at each stage of scenario expansion to ascertain how they framed and re-framed their views in light of the additional information and the position (positive or negative) that they took towards the scenario. Thus, developing and expanding the scenarios in this way enabled an understanding

[9] The scientist often drew simple diagrams with a pen and paper and referred to document images to aid his explanation. Video recording was useful in capturing the scientist's use and consumers' understanding of these resources.

[10] The scenarios were developed following a review of literature, project team deliberation and consultation with the participating scientist, predominately during the pre-discourse interview.

[11] The scientist stressed that the scenarios were hypothetical to ensure that the consumers understood that the risks and benefits presented were, in effect, discussion points and the product examples were not currently available on the market.

of consumers' 'flexibility of positioning' (Murphy, 2008) in terms of their attitudes towards food applications of nanotechnology.

3.4 Post-Discourse Reflective Interviews

Post-discourse interviews were undertaken by the lead researcher with the participating consumers to determine the extent to which they re-framed their attitudes towards nanotechnology after participating in the discourse and the extent to which any such re-framing led to attitude modification. The overall influence of the discourse and new information on consumers' attitudes and acceptance could then be evaluated. In addition, the consumers completed a brief questionnaire which addressed their attitudes towards and acceptance of food applications of nanotechnology; the findings of which are compared to the qualitative findings. Detailed thematic analysis was undertaken on the discourse and interview transcripts with the support of a computer assisted qualitative analytical package (NVivo 8).

4 Findings

In this section, the major emerging themes are considered. Participants' initial awareness and attitudes are reported. Following this, the factors framing attitudes and acceptance of nanotechnology are discussed.

4.1 Initial Awareness and Attitudes towards Nanotechnology

The pre-discourse interview with participating consumers confirmed that they were unaware of the concept of using nanotechnology in food production. As expected, given their low level of awareness, participants were unable to list any potential benefits or risks associated with food applications of nanotechnology. However, three of them were familiar with nanotechnology applications in other sectors, including medicine, computers and machinery and reacted positively towards its use within these sectors[12]. The word 'nanotechnology' was associated with images of 'tiny robots', things that were 'small or compact' and was linked with computers and mobile phones. While positive towards these images, several participants reacted somewhat negatively towards the concept of using nanotechnology in food production. In particular, nanotechnology was associated with *"lots of processing being done to food"* (CN4, Pre-Discourse Interview) resulting in unnatural food products. This finding supports the argument by Kahan *et al.* (2007) that the word 'technology' may influence perceptions of nano'technology'. In the absence of any information on nanotechnology, some participants reacted negatively when asked if they would purchase or consume nano foods: *"If I saw the word right now today I wouldn't go near it"* (CN4, Pre-Discourse Interview). Others had a more measured reaction: "*I wouldn't avoid it but I would be wary of it"* (CN5, Pre-Discourse Interview). Interestingly, several participants commented that their initial attitude and scepticism towards nano foods was framed by their lack of knowledge about nanotechnology, illustrating that their attitudes were weakly formed and potentially flexible. Finally, participants' familiarity with nanotechnology applications in other sectors appeared to positively frame their attitudes towards purchasing and consuming nano foods: *"I don't think I'd avoid it. I think I would be happy enough to purchase something [a food product] with nanotechnology in it"* (CN1, Pre-Discourse Interview).

[12] In fact, the participant who was familiar with the use of nanotechnology in machinery had previously purchased and used 'nano batteries' for power tools in his occupation as a carpenter.

4.2 Factors Framing Attitudes towards Nanotechnology

The factors and subjective values framing participants' attitudes towards the nanotechnology applications varied, depending on their individual perspectives towards the information presented. While participants often took that same overall position towards a scenario (positive or negative), they often framed their position differently and use different rationalities in deriving their position. In fact, a wide spectrum of perspectives was evident among participants. However, several common themes did emerge in terms of the factors framing acceptance.

The dynamic (trust, rapport) between the participants and scientist played a role in influencing their attitudes and acceptance of nanotechnology. Based on the various pieces of evidence, including video analysis of non-verbal gestures, the scientist appeared to be effective in building a rapport and interacting with participants, thus ensuing they felt comfortable expressing their opinions[13]. During the discourse, the scientist often referred to and built on information that participants provided in an effort to build a 'common ground' on which to relate to them. Furthermore, he framed examples and information within the context of the environment that surrounds the participant. The fact that the scientist was considered capable of bringing *"a very high level concept really you know down to very simple language for a lay person"* (CN3, Post-Discourse Interview) and *"personable"* and *"open"* towards listening to the participants' views may have positively framed their attitudes towards nanotechnology. Furthermore, the participants appeared to place a significant amount of trust in the information the scientist presented, due to his 'expert' status, which may also have positively influenced their attitudes.

Product Characteristics – Demands from Food Products

Beneficial product characteristics associated with health and taste framed participants' responses positively. In particular, additional health benefits (by the removal of an unhealthy ingredient or the addition of a health promoting ingredient) without compromising taste were welcomed with reactions such as "*amazing"* and "*brilliant".* This underlies the importance of these two attributes to the individual and the perceived sub-optimal trade-offs they currently make due to lack of choice. Benefits were framed at both the personal and societal level. As previously mentioned, at the personal level, this was based on potential future health gains without immediate enjoyment losses. This was extrapolated out to the societal level, where the use of such products was seen to offer a potential enhancement to 'the health of the nation'. However an initial perceived trade-off was observed with the naturalness of the product being compromised: *"lots of processing being done to food"* (CN4, Pre-Discourse Interview). This position changed, somewhat, when the scientist suggested that the application of nanotechnology is a natural process that involves only the use of technology and no artificial additives: *"I mean it's something that is pretty much naturally occurring anyway you know (…) you add technology to it, but it's not adding anything that I can see that's unbeneficial"* (CN1). However, naturalness along with freshness and healthiness came to the fore when discussion centred on the use of nanotechnology to increase food safety and extend shelf life (through nanotechnology-based smart packaging). While the promise of an extended shelf life was seen to offer convenience, and thus framed attitudes positively, for some participants, perceived

[13] In particular, video analysis was useful in confirming how comfortable participants were in interacting with the scientist (e.g. expressive use of hand movements versus poor eye contact), how well they understood his explanation (e.g. nodding of head to illustrate comprehension versus a blank stare) and how emotive they were in reacting to the information presented (e.g. frowning versus limited facial movements).

naturalness, freshness and healthiness losses countered this benefit. Furthermore, some referred to the full supply chain to infer that food could be manipulated at every stage, resulting in an unnatural product which created a source of worry: "*I would worry about the amount of layers of nanotechnology that are in everything, right from the initial start of production, right through to human consumption or usage"* (CNP1, Post-Discourse Interview).

The trade-offs between benefits and costs also formed part of the initial framing for acceptance or rejection. Premiums (up to 25%) were accepted (if personal health benefits were apparent) at the individual level and thus did not cause a reassessment of participants' position about the technology: "*In general, I suppose if the health benefits far outweigh the other products on the market then I think you would be happy to pay …"* (CN1). However when considered at the societal level, the premiums were consider a barrier to achieving an enhanced health status for the nation: *"I suppose for me it [the price premium] wouldn't really be a big issue, but I would suspect that for many people it would be …cost factor would be huge*" (CN3).

Concern with safety was pervasive. A condition of acceptance of using nanotechnology in food production was that any potential risks associated with nano foods would be *"straightened out"* and removed: *"If the risks are removed then people will be interested"* (CN3). The need for adequate regulation and risk assessments were stressed and *"rigorous testing"* was demanded. Evidence of the need for a precautionary approach was clear within the discourses: *"it's all about being tried and tested"* (CN4). Acceptance was therefore framed by the assumptions that any potential risks would be addressed before such products reach the market and that any stated health claims would be validated. Participants did, however, acknowledge that it is challenging to determine all of the unknown risks potentially associated with applications of nanotechnology. Discussion about uncertainty regarding potential negative outcomes from the consumption of nano foods presented as a clear 'tipping point' in acceptance: *"I would have serious reservations if that was the case"* (CNP1). While acceptance of benefits (e.g. health benefits) was framed around the specific nano food product in question, the suggestion of a potential risk associated with one application appears to have consequences across all potential products. This illustrates that risk communications about a specific nanotechnology application can negatively frame attitudes towards a different application.

Individual Relevance, Perspectives and Characteristics

As indicated above, the characteristics of the products impacted the acceptance/rejection of nano foods; however differences amongst individuals framed the level of acceptance. Personal relevance of the nano food product's attributes to the individual's life generally resulted in a more positive and emotive response. For example, health benefits, taste benefits, and extended shelf life were welcomed when they were aligned to personal, relevant goals. Those who believed that satisfactory solutions already existed within the specified product category were not as open-minded about nanotechnology applications within the category. The emotive nature of the nanotechnology applications to the individual also impacted on their responses, as illustrated with some participants viewing smart packaging (nano-outside applications) as less exciting than nano-inside food applications: "*it's just not something I would find as exciting or interesting as the actual food itself"* (CNP1). Furthermore benefits that were not viewed as accruing to the participant (e.g. nanocoatings on equipment) received a more muted response "*I mean the coating is really only of benefit to the manufacturer*" (CN5).

The desire for control and freedom of choice framed acceptance for some: "*If there was warnings on the label with the health risks as well as the benefits I suppose then that's fair enough"* (CN1). Thus, acceptance was conditional on the provision of comprehensive labelling. The strength of this perspective was evident in the post-discourse questionnaire which found that 6 of the 7 participants felt that they would be unhappy if served nano foods in a restaurant without prior knowledge. However, perceived control was not only associated with freedom of choice. Some participants viewed nanotechnology as enhancing their control. In particular, smart packaging was perceived by some to increase their control over food quality and safety. Conversely, one participant believed that smart packaging was unnecessary, as they felt they had adequate personal control over the freshness, quality and safety of food products purchased.

In terms of participants' attitudes and values, general risk sensitivity framed individuals' reactions to the hypothetical risks presented. In particular, some participants displayed low risk sensitivity, expressing a somewhat fatalistic view about the risks: *"There are risks with everything"* (CN4). Others were more risk averse displaying significant concerns which negatively framed their attitude towards accepting nano foods. Furthermore, some participants' attitudes were framed, either positively and negatively, by their attitude towards science and technological progress. For example, one participant, who was particularly positive about nanotechnology, continually identified themselves as a techno-enthusiast, supportive of technological progress: *"I would be…kind of open-minded as regards new technologies"* (CN1). *"I think it's far better to have the technology than not. Because who knows what else it will lead onto like"* (CN1, Post-Discourse Interview). Even when presented with hypothetical risks, their positive attitude towards technological progress framed their reaction: *"Initially there might be issues. But I mean the future technologies that we could get out of it could be something amazing (…) I think I am still fairly positive about it"* (CN1).

A clear framing that emerged, during the scientist's explanation of nanotechnology and its food application, was based on the experience and background of the individual participant. Those with technical backgrounds (in the case of this research, a carpenter and a qualified aeronautical engineer/pilot) used these as a basis for attempting to understand nanotechnology. Those without a technical background appeared less capable of framing nanotechnology within any context. In fact, they often stressed their non-technical and non-scientific background as a means of pre-emptively justifying their potential lack of understanding. Furthermore, although they indicated they understood the technology, they were less able to ask clarification questions.

Interestingly, at times participants did misinterpret or fail to accurately comprehend the information presented. Participants' awareness of the use of nanotechnology in other sectors was a potential anchoring bias, framing their (mis)understanding of food applications of nanotechnology. For example, although a participant exhibited high comprehension capabilities, they failed to fully comprehend a key premise of nanotechnology; i.e. that it is a measurement of scale and its applications vary significantly across sectors: *"If they are using nanotechnology in batteries and they are using it in food, it would kind of concern me. Because they are two totally different industries. And you are consuming food…and they are using the nanotechnology in batteries as well"* (CN5, Post-Discourse Interview).

Participants' knowledge about food related issues, including regulation, appeared to positively frame their attitudes (particularly their risk assessments) towards nano foods. They spoke of food products undergoing safety assessments before being introduced onto the market and having to comply with regulatory standards: *"there are so many tests involved in releasing a new food now and a new technology, that to get it onto the market would actually nearly guarantee (…) that the food technology would be safe"* (CN1). Trust in these processes, and in the government and regulators to protect them and the public from unknown risks was evident: *"I probably would trust the government on it if they had done their research and reckoned it was OK"* (CN5).

Familial Relevance

The perceived impact of nanotechnology applications on individuals' families was a predominant framing factor. In particular, attitudes were often framed based on how these applications could support better health of participants' families. For example, one participant felt that nano foods with non-discernable health promoting ingredients were especially useful for children who may not like the taste of such ingredients. Clearly, this participant's family status (as a father of three young boys) framed his attitude towards such products. In addition, family status appeared to frame some participants' attitudes towards using nanotechnology to extend shelf life. For example a married participant with no children perceived smart packaging to personally benefit her, given her small family, but not to be as beneficial for larger families. Furthermore, the impact of potential risks on family members, particularly young children, was cited as a concern often framing risk assessments: *"I wouldn't be inclined to take it then or give it to my grandchildren. I would judge everything now on my grandchildren you see"* (CN3).

Societal Perspectives

Interestingly, participants felt that, subject to any associated risks being adequately addressed; nano foods should be available to purchase, as a result of associated societal health benefits: *"If it [a health promoting nano food] will improve people's lives, well and good"* (CN3). Furthermore, as previously illustrated, participants often compared the impact of nanotechnology applications on themselves personally with others in society. In particular, some participants made inferences about societal reactions when actually referring to their own reactions, e.g. willingness to accept a price premium on nano foods: *"I don't think people would buy it if it [the price] was put up"* (CN2, College Student). Others perceived their personal framing of information to differ to those in society.

Environmental Perspectives

Some participants were more concerned about environmental issues than others and this positively framed their attitudes towards smart packaging that reduced waste. However this positive position was reassessed by the suggestion that such packaging may not be biodegradable and may be difficult to recycle. Ethical concerns framed one participant's position; they suggested that as citizens "*we have a responsibility to address environmental risks like this*" (CN3). Equally, participants' lack of concern for environmental risks positively framed their attitudes towards smart packaging; they considered the benefits (e.g. increased shelf-life, food safety) to outweigh the potential risks: *"…that's [the environmental risks'] quite a negative side to it but (…) there's so many positives with the packaging*" (CNP2). In fact, some participants expressed somewhat fatalistic views towards the environmental risks: *"I mean most of the packaging now isn't eco friendly at all anyway (…) that wouldn't be a major concern*

for me, because…I know it's kind of a dark view but we are already pumping stuff into the environment that's not doing it any good anyway" (CN1).

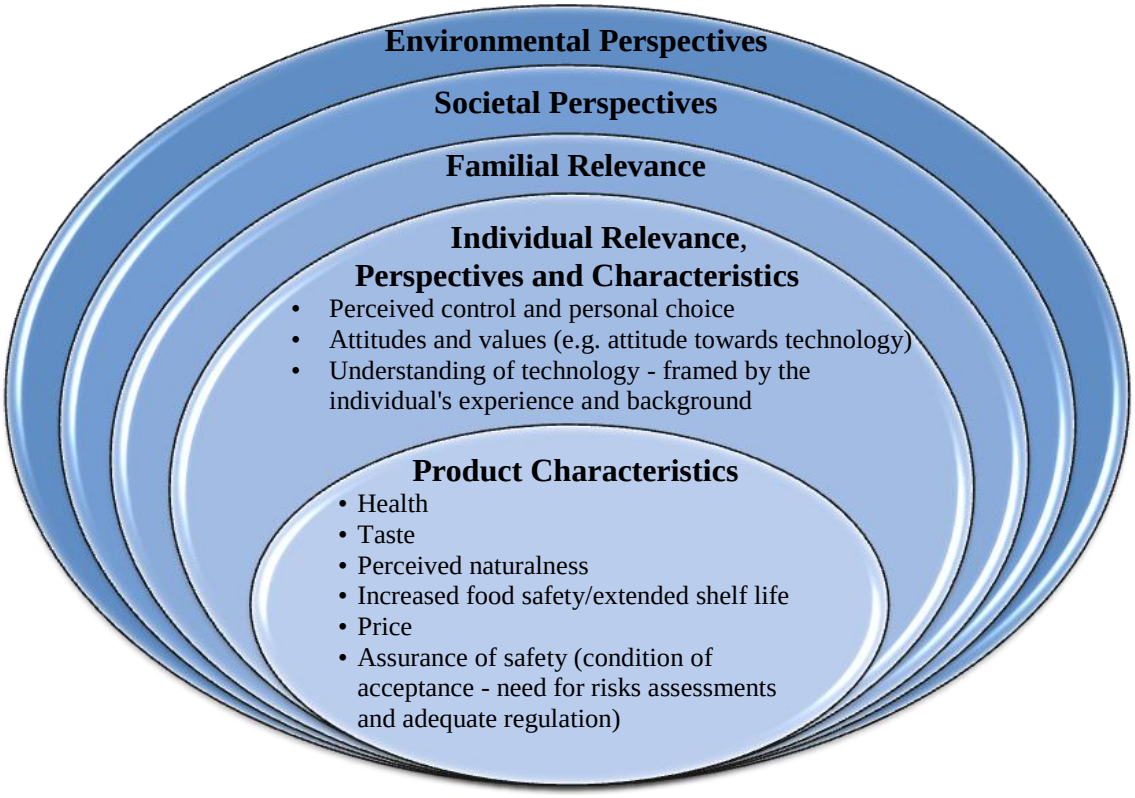

Figure 1. Factors Framing Consumer Acceptance of Food Applications of Nanotechnology

Figure 1 summarises the key factors that framed participants' attitudes and acceptance of food applications of nanotechnology. The extent to which these factors framed attitudes and acceptance varied. In particular, some participants framed their attitude via a broad lens that incorporated the impact of nanotechnology applications on society and the environment (i.e. the outer circles). Conversely, others focused predominately on the personal relevance of the hypothetical nano food products or applications to them as individuals (i.e. the inner circles).

4.3 Acceptance of Nanotechnology

While, the feedback from participants should be interpreted with caution, as it may have been positively framed due to the nature of the research, some interesting insights can still be drawn. The various pieces of evidence confirm that participants' attitudes towards nano foods became more positive as a result of participating in the discourse, in spite of the hypothetical risks presented: *"The more information I got, the more positive I was about it"* (CN1, Post-Discourse Interview). Therefore, additional information, of both risks and benefits, appears to have positively framed participants' overall attitude towards nanotechnology. Furthermore, the majority of participants felt they were confident in their assessments of nanotechnology after participating in the discourse and confirmed that their attitudes formed during the discourse had not changed since participating in the discourse. This indicates that their positive attitudinal formation was not temporary. The post-discourse questionnaire also confirmed that participants were more likely to purchase nano foods after participating in the discourse and

that they approved of using nanotechnology in food production[14]. Although the hypothetical risks presented were potential 'tipping points' in acceptance, the majority of participants considered the benefits of nano foods to outweigh the potential risks.

However, some felt that this would depend on the nanotechnology application in question. Cobb & Macoubrie (2004) also found that in spite of their limited knowledge about nanotechnology, the American public appears to consider the benefits of nanotechnology applications in general to outweigh potential risks. In summary, participants appeared to be generally accepting of using nanotechnology in food production, subject to any associated risks being adequately addressed. One participant effectively summated the issues they perceived to surround consumer acceptance of nano foods: *"It's interesting. It will bring benefits. It will bring problems. That's life"* (CN3, Post-Discourse Interview).

5 Discussion

While participants were unfamiliar with the concept of using nanotechnology in food production, in general, new information appeared to positively impact their attitudes towards food applications of nanotechnology. This increased their perceived likelihood of purchasing nano foods. The hypothetical scenarios revealed key 'tipping points' in acceptance and conditions of acceptance of nano food applications, both generally and specifically. Participants were more accepting of the different nanotechnology applications if they perceived the associated personal and societal benefits to outweigh the potential risks. Siegrist *et al.* (2007a) also found perceived benefits to be an important predictor of willingness to purchase nano foods. In fact, Siegrist *et al.* (2008; 2007b) found that individuals who perceive greater benefits to be associated with nano foods, perceive fewer risks to be associated with such products. Similar to the findings of Siegrist *et al.* (2008), the risk and benefit perceptions of participants were not homogenous. For example, some consumers were more accepting of using nanotechnology in food packaging (nano-outside) than in food processing (nano-inside) and vice versa, depending on the perceived personal relevance of such applications.

Overall, the findings revealed that product characteristics including perceived personal and societal health benefits, taste, perceived naturalness, price and shelf life framed consumers' attitudes and overall acceptance. These findings mirror those of Siegrist (2008) and Siegrist *et al.* (2008). In some cases, the presence (e.g. of a perceived health benefit) or absence (e.g. of a price premium) of these attributes was a potential 'tipping point' or condition of acceptance. In addition, subjective values such as the perceived individual relevance of such nano foods, individual risk assessments, heuristics including trust in stakeholders and personal control, individual characteristics including general risk sensitivity and attitudes towards technology framed consumers' attitudes. Siegrist *et al.* (2007a, b; 2008) also found the aforementioned factors to be important determinants of acceptance of food applications of nanotechnology. Finally, familial relevance of such applications, and societal and environmental factors framed attitudes and ultimately acceptance of nanotechnology applications.

Acceptance was conditional on potential risks being adequately addressed before nano food products reach the market and the stated health claims being validated. This brings the issue of trust into clear focus and raises the question of what 'adequately addressed' means.

[14] Only one participant, who displayed the greatest general risk sensitivity, oscillated between approval and disapproval.

Furthermore, similarly to Yawson & Kuzma (2010), the findings indicate the complexity of the numerous factors framing consumer acceptance of nanotechnology. For example, some participants displayed conflicting views, considering safety assurance a condition of acceptance, while at the same time, expressing fatalistic views about some of the risks presented.

The findings presented illustrate some of the challenges interested parties faced in communicating to the public about food applications of nanotechnology (Bostrom & Lőfstedt, 2010). In particular, industry and institutions involved in food risk communications should be cognisant that consumers may draw on past experience or knowledge of nanotechnology applications in other sectors when evaluating the risks and benefits associated with food applications. This can potentially lead to misinterpretation of the processes that food undergoes. Therefore it is important to reiterate to consumers in future risk communications that; nanotechnology is a measurement of scale, its applications across sectors may differ considerably and that the potential risks associated with in-organic nanoparticles differ to those of organic nanoparticles. Furthermore, potential risks associated with a specific nanotechnology food application may frame consumers' overall risk perceptions of nano foods.

Labelling a product as 'nano' without informing consumers about what nanotechnology involves could negatively impact acceptance, as it may be interpreted as a warning about potential risks (Siegrist, 2008, 2010). The media will play an influential role in framing consumers' attitudes and acceptance of food applications of nanotechnology (Dudo *et al,* 2011; Siegrist, 2010). If the media portray such applications in a negative light and nano foods are labelled accordingly, there could be widespread rejection of such products, based on a fear of unknown potential risks that may not actually be associated with nano foods. In addition, as previously illustrated, trust in information sources, including the food industry and the regulatory system will be important determinants of consumer acceptance of nano foods (Siegrist *et al.,* 2007a; 2008). The current regulatory processes in place with regard to nano foods should also be clearly communicated to consumers (Bostrom & Lőfstedt, 2010). Finally, in any risk communication, openness, transparency and consumer engagement is necessary (House of Lords, 2010).

If the objective of a risk communication is to ensure consumer acceptance, a focus on benefits to the consumer (particularly novel health benefits that do not compromise taste) (Siegrist *et al.,* 2007a) and highlighting that the use of nanotechnology in food processing is a natural process, involving no artificial additives (Siegrist, 2008), may positively influence acceptance of nano-inside foods. However, ignoring any potential risks could cause a very negative reaction. Communications on nanotechnology should anchor benefits of nano-inside foods in concrete examples of product characteristics that are relevant to consumers' demands from food.

5.1 Study Limitations

As a small number of consumers (n = 7) participated in this study, the findings presented are by no means representative of Irish consumers. However, depth was achieved through the use of three data points for each participant and as a result, the significant diversity in the factors framing participants' attitudes and acceptance of food applications of nanotechnology was evident. Another potential limitation is that the outcomes observed were framed by the information (including the hypothetical risks and benefits and nanotechnology applications) presented. However, the breadth of observations from participants with regard to responses to

the scenarios militates against this limitation. Furthermore, participants' attitudes towards the hypothetical nano food products discussed may have been somewhat abstract and not reflect their true actions in a real life purchase or consumption situation.

6 Conclusions and Further Research

The methodological approach (deliberative discourse) proved useful in revealing the multiple factors (including awareness, attitudes and subjective values) framing consumers' attitudes, and ultimately acceptance (or rejection), of different food applications of nanotechnology. The influence of new information on acceptance and the evolution of consumers' attitudes were explored. The presentation of the scenarios enabled an understanding of the flexibility of consumers' attitudes and their willingness to re-frame their attitude in light of additional information. The scenarios also revealed potential 'tipping points' in acceptance, and the construction of meaning around information about nanotechnology. This research also suggested some suitable messages and approaches for industry and institutions involved in food risk communications to provide consumers with information to aid their evaluations of nanotechnology.

This methodological approach (i.e. deliberative discourse) has also been adopted to examine consumer acceptance of several other NFTs. The findings across all of the discourses will be compared and contrasted, to confirm if common factors frame consumer acceptance of these technologies. Furthermore, the findings of this paper will aid in the design of a large (nationally representative) survey examining Irish consumer acceptance of NFTs, including nanotechnology, in a broader context.

Acknowledgements
This FIRM (Food Institutional Research Measure) project is funded through the Department of Agriculture, Fisheries and Food under the National Development Plan 2007-2013.

Note
Quotations from the deliberative discourses and interviews have been edited and irrelevant exclamations and repetitions are omitted. When words or sentences are omitted this is indicated with a bracketed ellipsis: (...). An ellipsis without brackets indicates a pause. Finally, text presented in square brackets represents implicit parts of the argument/conversation, expressed in the preceding discussion.

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Appendix 1

Nanotechnology Summary Sheet Distributed to Participating Consumers

Food technologies such as pasteurisation, homogenisation and drying/dehydration have been used for many years in the production of foods. New and advanced technologies are constantly being developed. Nanotechnology is one of these novel food technologies.

Nanotechnology is the experimental process of manipulating and controlling matter (particles) at dimensions between approximately 1 and 100 nanometres (at a scale of 1/100th the width of a human hair), where unique phenomena enable novel applications[15].

- A nanometre is one-billionth of a metre (the sheet of paper that you are holding is about 100,000 nanometres thick).
- Dimensions between approximately 1 and 100 nanometres are known as the nanoscale. Unique physical, chemical, and biological properties can emerge in materials at this scale.
- In addition to being engineered, nanoparticles are also naturally occurring. For instance, the human body uses natural nanoscale materials, such as proteins, to control the body's many systems and processes. Other examples are nanoscale fibres that give meat/muscle its structure and nanoscale particles that make milk appear white.
- There are different types of nanomaterials which derive their names for their individual shapes and dimensions (i.e. particles, tubes, fibres and films that have one or more nanosized dimension).
- In recent years scientists have been researching how different types of nanotechnologies can be applied in food products, production and packaging.

[15] http://www.nano.gov/html/facts/whatIsNano.html

Appendix 2

Hypothetical Nanotechnology Scenarios Presented to the Consumer during the Discourse

1. Potential Applications to Food/Beverages - Reducing Unhealthy Ingredients without Compromising Taste
• **Scenario 1A: Nanotechnology could be used to develop a low fat butter that tastes the same as full fat 'real butter'. This would involve putting nanosized water droplets inside fat droplets which are then inside a continuous water phase (a 'water in oil in water' (wow) system). Nanotechnology can also be used to make food products healthier for consumers, by reducing the salt, fat and sugar content without compromising the taste, which would also have societal benefits.**
• **Scenario 1B: In addition to these benefits, there are some concerns about using nanotechnology in food production. As nanotechnology is expensive for industry to employ, there would be a price premium for products made in this way (e.g. a 25% premium).**
2. Potential Applications to Food/Beverages - Adding Health Promoting Ingredients to Improve Nutritional Value
• **Scenario 2A: Nanotechnology can be used to add vitamins, nutrients, medicines or supplements to everyday foods and beverages. This involves developing nanosized carriers or materials, in order to improve the absorption of such added materials. For example, nanoencapsultaion can be used to add antioxidants from tea to a range of food products. Taste, texture and appearance are unaffected. Nanotechnology could potentially offer wider benefits to society by offering healthier food options.**
• **Scenario 2B: There are concerns, however, that the implications for human health of using nanotechnology in food production remain uncertain. In particular, little is known about how the body will react to and break down nanosized materials. Opponents argue that certain nanomaterials may not break down in the stomach and may have the potential to leave the gut, travel through the body and accumulate in the cells with long-term effects which cannot yet be determined. Therefore a food ingredient that is currently generally recognised as safe could have unintended consequences at the nanosize.**
3. Potential Applications to Food/Beverage Packaging to Improve Food Safety, Shelf Life and Reduce Waste
• **Scenario 3A: Nanotechnology can be used to produce 'smart packaging'. Through this technology, nanosensors can detect food bacteria and alert consumers to the deterioration of food resulting in more accurate use-by dates. Nanotechnology also enables the use of lighter, stronger and more effective materials resulting in more environmentally friendly products, which require less packaging, thereby reducing waste.**
• **Scenario 3B: In addition, nanotechnology can be used in 'smart packaging' to make foods and beverages safer and extend shelf life e.g. nanocomposites in anti-microbial packaging can help prevent the growth of bacteria in food by absorbing oxygen. These food products could potentially become cheaper due to reduced transportation costs.**
• **Scenario 3C: There are concerns about the potential implications of leaching of nanocomposites from food packaging to products. In particular, there are concerns about the implications for human health of ingesting some nanomaterials e.g. nanosilver (its potential toxicity/ risk of bio-accumulation in the body).**
• **Scenario 3D: Opponents argue there are concerns about the antibacterial properties of nanosilver continuing to work when deposited in watercourses or sewage treatment works, posing a threat to healthy (or artificial, in the case of sewage plants) ecosystems. Similarly, increasing the complexity of packaging materials might in turn make such packaging more difficult to recycle and thus actually increase waste.**
4. Potential Applications to Food Production to Improve Food Safety and Efficiency
• **Scenario 4A: Nanocoatings can be applied to food processing machinery to improve food safety. Such machines will need less cleaning, involving less downtime. Reductions in the build-up of deposits on pipes and heat exchangers may result in a more energy efficient process. Consumers may benefit through a price reduction in products processed in this manner.**
• **Scenario 4B: However, the implications of using such nanocoatings for human health or the environment remain unclear.**