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

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.

Keywords: Nanotechnology acceptance; expert opinion; societal response; international comparison

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 & 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 & Rowe 1996) and genetic modification (Frewer *et al.* in press; 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 & 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, and in what sequence (Gupta *et al.* 2012). Expert views on societal desirability of nanotechnology applications are likely to be reflected in the 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 societal introduction of products based on nanotechnologies. On the one hand, experts may erroneously predict that a specific application is societally desirable, while in fact society is negative about the product. This might easily result in the development of products that do not meet expectations of the developing company and might trigger societal protest against nanotechnology as a whole. On the other hand experts fearing societal response may hold back on developing products that society wants or needs. It is important that expert views on

Comment [ARHF1]: Dudo, A., Choi, D-H, & Scheufele, D.A. (2011) Food Nanotechnology in the new. Coverage patterns and thematic emphases during the last decade. *Appetite.* 56, 78-89

societal response to nanotechnologies are explicit as that will allow investigation of potential mismatches between experts and consumers view on acceptability of nanotechnology applications. 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; Fischhoff *et al.* 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 to 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.* ~~in press~~2013).

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.

In spite of the limited success in predicting the adoption of new technologies based on the introduction previous technologies, it appears that e~~E~~xperts ~~may~~are often~~, in turn, be~~ influenced ~~not only by local economic and regulatory conditions, but also local experiences of~~by societal responses to preceding technologies, and that these previous experiences influence their behaviour in the current situation. Nanotechnology, related to~~, as it was the case with~~ genetic~~ally~~ modification~~ed~~ (GM) ~~foods~~. As the GM debate has mainly focussed on societal resistance against food, responses to nanotechnology in food are probably important indicators for the debate on societal acceptance or rejection of nanotechnology.

Expert risk assessment of GM food has led to the emergence of different risk governance structures internationally (Table 1). Experts have been involved in different local weighing of economic, social and environmental consequences of GM food. 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 (Andree 2002; Carter & Gruere 2003; Knight *et al.* 2008; Prakash & 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 (Anderson & 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 (See for e.g. India and Singapore). The development of different regulatory frameworks is likely to echo differences in local expert debates. Hence the extent, to which expert views vary according to local socio-economic factors and the local discourse, is important when considering the introduction of nanotechnology in food.

Nanotechnology and its applications ~~can pose similar situation as has been the case~~have several similarities with GM food commercialisation, for example, in being an enabling, invisible technology (David & Thompson, 2011; Mehta, 2004). The comparison between the societal unrest surrounding GM food and nanotechnology in food has been frequently made (see inter alia te Kulve et al. (in press), Thompson, 2011; Kuzma & Priest, 2010). There are however, also differences between the history of GM and nanofood~~emphasizing the need to assess expert view on public perception of nanotechnology~~. One of the mistakes in the introduction of GM, was the focus on farmers as end-users of the product around 1990, and the almost complete neglect of consumers at that time. In nanotechnology such a focus on producers as endusers is currently not, or not yet, the case (Sparling, 2011). Indeed, it appears that there is considerably more public engagement in the development of nanotechnology making rejection less likely and the analogy with GM far from perfect (Sandler & Kay, 2006). Nevertheless if experts adopt reasons and priorities to accept nanotechnology that do not align with consumer views on food for example regarding perceived naturalness (Thompson, 2011), perceived lack of control and uncertainty about future consequences (Macnaghten, 2011) a negative public opinion may easily arise. In the United States, for example, it has been shown that the public considers religion an important issue in their evaluation of nanotechnology, while experts base their evaluation of nanotechnology in their trust in the science behind it (Ho, et al. 2011). The current expert views ~~Understanding expert views~~ regarding factors influencing the acceptance of technological innovation give insight in the extent to which different elements of nanotechnology are weighed by experts. The more certain experts are about the rating of a

Comment [ARHF2]: David, K., & Thompson, P. B. (Eds.). (2011). *What Can Nanotechnology Learn from Biotechnology?: Social and Ethical Lessons for Nanoscience from the Debate Over Agrifood Biotechnology and GMOs.* Academic Press.
Mehta, M.D. (2004) From Biotechnology to Nantechnology: What can we learn from earlier technologies? *Bulletin of Science, Technology & Society* 24 34-39

Comment [ARHF3]: te Kulve, H., Konrad, K., Palavicino, C. A., & Walhout, B. (in press). Context Matters: Promises and Concerns Regarding Nanotechnologies for Water and Food Applications. *NanoEthics*.

Kuzma, J., & Priest, S. (2010) Nanotechnology. Risk, and Oversight: Learning lessons from related emerging technologies. *Risk Analysis.* 30(11) 1688-1698

Thompson, P. B. (2011) Nano and Bio: How are they alike? How are they different In: David, K., & Thompson, P. B. (Eds.). (2011). *What Can Nanotechnology Learn from Biotechnology?: Social and Ethical Lessons for Nanoscience from the Debate Over Agrifood* ...

Comment [ARHF4]: Sparling, D. (2011) A framework for translating biotechnology experiences to nanotechnology In: David, K., & Thompson, P. B. (Eds.). (2011). *What Can Nanotechnology Learn from Biotechnology?: Social and Ethical Lessons for Nanoscience from the Debate Over Agrifood* ...

Comment [ARHF5]: Sandler, Ronald and W. D. Kay (2006), "The GMO-Nanotech (Dis)Analogy?," Bulletin of Science, Technology & Society, 26 (1), 57-62.

Comment [ARHF6]: See above

Comment [ARHF7]: Macnaghten, P. (2011) From Bio to Nano: Learning the lessons, interrogating the comparisons In: David, K., & Thompson, P. B. (Eds.). (2011). *What Can Nanotechnology Learn from Biotechnology?: Social and Ethical Lessons for Nanoscience from the Debate Over Agrifood* ...

Comment [ARHF8]: Ho, S.S., Scheufele, D.A., & Corley, E.A. (2011) Value predispositions, mass media, and attitudes toward nanotechnology: The interplay of public and experts. *Science Communication* 33(2) 167-200

nanotechnology and the more importance they attach to the rating, the more likely this will influence their response and subsequent actions in communicating about, and further development of nanotechnology products. ~~, 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.~~

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Table 1 about here

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Previous research has assessed expert views of the factors driving societal acceptance or rejection of nanotechnology. 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.* 2007; Yawson & Kuzma 2010). Gupta et al. (2012) 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. Given that nanotechnology is still evolving and "under construction", it is often characterised by both social and scientific uncertainties.

While there is by now a considerable body of research on how experts rate nanofood applications on different factors related to societal reponse to nanofood, there is little information which factors weigh most in their decisions. Therefore, there is a need to assess the extent to which experts ~~are certain about whether~~consider an issue ~~is~~ important in determining societal acceptance ~~and~~ as well as sampling their ~~own~~ uncertainty regarding their opinion regarding its direction of impact or salience.

Secondly, previous expert research has focussed on single geographical locations. However, as the GM debate has shown, different expert discourses in different locations has resulted in un-harmonised regulations. If we assume that experts base their approach to nanotechnology, at least in part, on local experience with the GM debate, it becomes of the utmost importance to identify differences between experts to make differences explicit, and allow a transparent and open global discussion to evolve in order to achieve consensus on harmonised regualtions.

Comment [ARHF9]: Of course we dont find this, but I think this would highlight the addition

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 in areas of the world with different innovation "cultures" 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~~ across ~~different geographic regions according to local variations in regulations and previous experience with technology acceptance?~~

~~4.~~ The research builds on that reported in Gupta et al (2012), which focused on a North Western European expert population, and utilised a repertory grid methodology. The research in the cuurent paper utilises experts from 5 distinctly different regions, and different innovation "cultures" are sampled and compared. The current research extends Gupta et al (2012) by assessing expert uncertainty about the relavnce of each determinat, and uncertainty regarding their responses. Both may be relevant to the development of an innovation strategy.

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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 & 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. 54% (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*. 2012). 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 5 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.

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 $F^{1}(3.35, 171.15) = 16.56$; $p<.01$. 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 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 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 *nanoencapsulated-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 3).

[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.

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, ($F(4, 51) = 0.49$; $p = 0.73$), nor was there an interaction between the certainty of expert's response for different applications across different countries ($F(12.89, 164.35) = 0.63$; $p = 0.19$). 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 2).

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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 *nanoencapsulated-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 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 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 *nanoencapsulated-food* than experts from India and Singapore. Similarly, experts from Australasia predicted *nanoencapsulated-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, ($F(4, 49) = 0.58$; $p = 0.67$) nor was there an interaction effect between the certainty of expert's response associated with different nanotechnology applications across different countries, ($F(15.27, 187.15) = 0.77$; $p = 0.71$). 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 nanoencapsulated-*food* than for the other applications (Table 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, $F(4, 45) = 2.24$; $p = 0.07$. There was no significant interaction between expert predictions regarding societal perceptions of need and region, $F(13.10, 147.45) = 1.34$; $p = 0.19$. Pairwise comparison (LSD) between applications showed that *targeted drug delivery* and *water filtration* are predicted to be perceived as societally more necessary, while *nanoencapsulated-food* was predicted to be perceived as less necessary (Table 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, ($F(3.29, 148.27) = 1.54$; $p = 0.19$) and no significant main effect of attributable to region, ($F(4, 45) = 0.77$; $p = 0.54$). There was no interaction effect between self-rated certainty of responses for different applications and region ($F(13.18, 148.27) = 1.04$; $p = 0.41$).

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, $F(4, 53) = 0.84$; $p= 0.50$. No significant interaction effect was found between societal concern and region, $F(14.87, 197.02) = 1.54$; $p = 0.08$. 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 *nanoencapsulated-foods* (Table 2).

A repeated measures ANOVA indicated no significant main effect of application influencing self-rated certainty of expert's responses ($F(3.95, 209.43) = 0.50$; $p = 0.73$) and no significant main effect attributable to region, ($F(4, 53) = 0.69$; $p = 0.60$). There was no significant interaction effect between the certainty of expert's response for different applications across region ($F(15.80, 209.43) = 0.89$; $p = 0.57$).

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, $F(4, 41) = 1.59$; $p = 0.19$. No significant interaction effect was found between timeframe and region, $F(13.57, 139.11) = 0.67$; $p = 0.79$. 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 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 ($F(4, 41) = 2.29$; $p = 0.07$) nor was there an interaction effect between the certainty of expert's response for different applications across regions ($F(14.54, 149.07) = 1.17$; $p = 0.29$). Pairwise comparisons (LSD) between applications show that experts were less certain regarding the availability timeframe for *smart pesticides* and *nanoencapsulated-food* than other applications (Table 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). 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.

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Table 4 about here

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Discussion & Conclusion

The research presented here provides evidence that the 5 factors identified by Gupta et al. (2012) are relevant outside of the European regulatory and cultural environment, at least in those regions included in the research, and potentially may be relevant to understand how expert anticipate~~ing potential~~ societal responses to different applications of nanotechnology. The experts indicated ~~that~~ they expect societal responses ~~will~~ to vary between different applications of nanotechnology, and will 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 *nanoencapsulated-food* and *smart pesticides* will be perceived as least beneficial, unnecessary and riskiest among 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 *nanoencapsulated-food*. Concerns about coming into contact with nanomaterials will be the greatest for *nanoencapsulated-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.

Assuming that expert opinion will shape the process of innovation and commercialisation, 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 less as risky than food (Te Kulve et al in press). 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.

Comment [ARHF10]: Ref listed before

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 (Gupta *et al.* 2012), 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 & 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.

Generally, expert views regarding societal responses to different applications of nanotechnology ~~were~~ were largely 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 were much more pronounced than the differences between countries. This might imply that at this moment in time the expert community holds a similar point of view on societal acceptability nanotechnology in foods around the world. If such expert views are predictive of the debate to follow, this would be a hopeful sign that the local differences that have emerged around the introduction of GM are going to be less dominant for nanotechnology. Further research is required to compare expert views from non-English speaking countries to provide a more comprehensive view on expert opinion on societal response to nanotechnology. Even within the currently studied countries, local differences may emerge if actual consumer views are shown to be different across different countries. In

the end expert views on societal response to a novel technology are more likely to be indicators of the paths towards development, introduction and communication about nanotechnology products than true reflection of public opinion. Therefore data of the public is necessary to be able to compare if, and if so, to what extent expert opinions are relevantly related to public acceptance of nanotechnology in food.

~~Further research is required to compare expert views from non-English speaking countries to provide a more comprehensive view on expert opinion on societal response to nanotechnology.~~ 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.

Appendix

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 (Nanoencapsulated-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)*

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