J Nanopart Res (2011) 13:4399–4410
DOI 10.1007/s11051-011-0473-1

PERSPECTIVES

Societal response to nanotechnology: converging technologies–converging societal response research?

Amber Ronteltap · Arnout R. H. Fischer · Hilde Tobi

Received: 17 March 2011 / Accepted: 21 June 2011 / Published online: 6 July 2011

Abstract Nanotechnology is an emerging technology particularly vulnerable to societal unrest, which may hinder its further development. With the increasing convergence of several technological domains in the field of nanotechnology, so too could convergence of social science methods help to anticipate societal response. This paper systematically reviews the current state of convergence in societal response research by first sketching the predominant approaches to previous new technologies, followed by an analysis of current research into societal response to nanotechnology. A set of 107 papers on previous new technologies shows that rational actor models have played an important role in the study of societal response to technology, in particular in the field of information technology and the geographic region of Asia. Biotechnology and nuclear power have, in contrast, more often been investigated through risk perception and other affective determinants, particularly in Europe and the USA. A set of 42 papers on societal response to nanotechnology shows similarities to research in biotechnology, as it also builds on affective variables such as risk perception. Although there is a tendency to extend the rational models with affective variables, convergence in social science approaches to response to new technologies still has a long way to go. The challenge for researchers of societal response to technologies is to converge to some shared principles by taking up the best parts from the rational actor models dominant in information technology, whilst integrating non-rational constructs from biotechnology research. The introduction of nanotechnology gives a unique opportunity to do so.

Keywords Nanotechnology · Societal response · Systematic review · Converging methods · Rational actor models · Affective determinants · Science and technology governance

A. Ronteltap (✉)
LEI, Part of Wageningen University and Research Centre, PO Box 35, 6700 AA Wageningen, The Netherlands
e-mail: amber.ronteltap@wur.nl

A. R. H. Fischer
Wageningen University and Research Centre, Marketing and Consumer Behaviour Group, Wageningen, The Netherlands

H. Tobi
Wageningen University and Research Centre, Research Methodology Group, Wageningen, The Netherlands

Introduction

Nanotechnology is an emerging technology, particularly, likely to be vulnerable to societal unrest as it is invisible, unnatural (cf. Slovic 1987) and can enter the body orally (through food), through the air (workplace exposure), and the skin (cosmetics). Uncontrollability, and secrecy (e.g. in military use, see Siegrist et al. 2007) can further enhance societal

feelings of discomfort. In addition, it is not clear who will get the benefits and who will suffer from the risks. In these aspects it shares many characteristics with other technologies. For example, comparisons with the introduction of genetically modified organisms (GMOs) are frequently made (MacOubrie 2006). A difference with GMOs and most other technologies, however, is that in the early stages of nanotechnology introduction many stakeholders have announced they are willing to seriously engage in the societal debate (The Royal Society and The Royal Academy of Engineering 2004). Although these intentions indicate a well-developed awareness of the importance of public response issues for nanotechnology, it remains to be seen how these relate to the actual nanotechnology.

In the past, not all technologies have lived up to the often high expectations of those inventing the new technologies. One of the reasons for failure of a technology may be societal resistance against a technology. A well-known example is the introduction of genetically modified foods, where societal resistance, particularly in Europe, resulted in reduced investments in research to further develop the technology, and has acted as a strong barrier against market introduction (Huffman et al. 2004; Schenk et al. 2008). The notion has grown that understanding societal response to new technologies may be essential to their chances of a successful introduction (Frewer et al. 2004). Over the last decades there has been a significant effort to gain more insight in societal response to new technologies (see e.g. Bainbridge 2002; Jacobs 2004; O'Hara et al. 2006; Ronteltap et al. 2007; Siegrist 2010). These studies have involved various disciplines within the social sciences (e.g. psychology and sociology). In addition, much of this research has been conducted in interdisciplinary environments where social scientists closely collaborate with natural scientists. This varied approach has resulted in a broad range of theoretical perspectives and has yielded many complementary insights. Recent reviews of previous research imply that within a particular application area (for example food, or information technology) specific theoretical perspectives are dominant, and that there is limited convergence over application domains (Gupta et al. 2011; Ronteltap et al. 2007).

With the increasing convergence of several technological application domains, as is the case for nanotechnology (Roco and Bainbridge 2005), convergence of different theoretical approaches in the research into societal response to such technologies has become overdue. However, to the best of our knowledge, a systematic overview that integrates insights from the social sciences across the different application areas is lacking.

This paper aims to show the current state of the societal response research by sketching the predominant approaches to previous new technologies. In a second systematic review, it studies the case of nanotechnology, and determines which approaches have been adopted in research into societal response to nanotechnology, and where convergence in studies of societal response of nanotechnology may be achieved. The systematic literature review method is applied, since it enables the synthesis of literature sources of various sorts into a robust, reproducible overview of social science approaches to previous technologies.

More specifically systematic literature reviews will be used to:

1. Identify the most influential theoretical approaches used to understand and predict societal response to previous novel technologies;
2. Identify which actors in societal response are most frequently studied;
3. Provide an overview of the emerging societal response research for nanotechnology;
4. Compare the approaches in nanotechnology with those of previous emerging technologies.

After concluding the systematic reviews, gaps in current research are discussed and suggestions for future directions of research into societal response to nanotechnology are given.

Methods

Review 1: societal response to previous novel technologies

The search for papers was conducted in the bibliographic database Web of Science, a subscription only online database listing journals in the ISI database for natural sciences (1945-present), social sciences (1956-present), and arts and humanities (1975-present). Because of these three domains, this database

covers a broad range of research disciplines in both natural and social sciences. To select all relevant publications reporting scientific research on societal response to new technologies, a search was based on four blocks of keywords. Block 1: 'the actor' was included to identify the publications dealing with end-users of technology. The second block: 'the object' included a broad range of technologies introduced in the last decades. Block 3: 'the dependent' ensured that included publications discussed acceptance or rejection and block 4: 'demarcation' limited the set of papers to those adding to theoretical knowledge whilst paying attention to societal relevance.

The construction of search terms was an iterative process, starting from a recent review on consumer acceptance of innovations (Ronteltap et al. 2007), extended by synonyms, abbreviations, and varieties. The resulting hits on a search term were checked against seminal papers within the knowledge of the authors. In addition, the abstracts of about 20 papers were scanned to see whether there was an acceptable proportion of relevant papers. Based on these findings, the search terms were broadened, limited or adjusted, until we decided on the final operationalisation.

In addition, to focus on peer-reviewed original insights, papers had to be original articles, review papers or discussion papers. For practical purposes, the papers had to be written in English. This resulted in a Boolean expression which was entered in the search function of Web of Science (Table 1).

The abstracts of the identified papers were quick-scanned for relevance, and papers were excluded if they were (a) not dealing with technology (e.g. papers on determinants of other types of behaviour, such as recycling), (b) not dealing with (a proxy for) response (e.g. papers only describing different groups in society) or (c) did not add in any way to theory-development or -testing (e.g. papers purely describing existing situations).

Based on the research aims, the structure of the coding scheme was developed. The papers were read in detail to further develop the coding scheme with emerging themes (bottom up), until a point of saturation was reached.[1] The main topics in the coding scheme were:

Table 1 Final search term societal response to new technologies

Block	Search term entered in Topic field
Actor	consumer* OR citizen* OR public* OR societal*
	AND
Object	"information technolog*" OR nuclear OR irradiat* OR vaccin* OR microwave* OR GSM OR "mobile phone*" OR UMTS OR RFID OR CO2-storage OR "chemical technolog*" OR pesticide* OR biotech* OR "genetic* modif*" OR GMO OR GMF OR GM OR genomics OR nanotech*
	AND
Dependent	"public reaction" OR "public response" OR attitude* OR perception OR opinion OR accept* OR reject*
	AND
Demarcation	(theory OR model OR framework OR concept OR paradigm) AND soci*
	AND
Other	Language = (English) AND Document Type = (Article OR Discussion OR Review)

An asterisk (*) is a wild card, a sign that can be replaced for any string in a single go. Quotation marks make sure of an exact use of the enclosed term, including spaces

1. Identification (e.g. year),
2. Type of research (e.g. whether or not empirical),
3. Application area (e.g. biotechnology),
4. Main theoretical approach (e.g. Technology Acceptance Model (TAM)),
5. Dependent variable (e.g. attitude),
6. Data source (e.g. individual consumers).

The final search was done on 28 September, 2009.

Review 2: societal response to nanotechnology

This systematic literature review was identical to the first review, except that in this review a specific Boolean expression for societal response to nanotechnology was created (see Table 2). The search term was broader to guarantee inclusion of early papers and communications and consisted of blocks 1: 'nanotechnology' to contain a reference to nanotechnology nanoparticles and 2: 'societal response' to contain a measure of response and 3: 'relevance' to be of societal relevance. The search was limited to the English language. The abstracts of the located

[1] Final coding scheme available on request from corresponding author.

Table 2 Final search term societal nanotechnology response

Block	Search term
Object	nanotech* OR nanopart*
	AND
Dependent	"public reaction" OR "public response" OR attitud* OR perception OR opinion OR accept* OR reject*
	AND
Demarcation	soci*
	AND
Language demarcation	Language = (English)

An asterisk (*) is a wild card, a sign that can be replaced for any string in a single go. Quotation marks make sure of an exact use of the enclosed term, including spaces

papers were quick-scanned on the same criteria as in the first review to exclude publications irrelevant to the research question.

The papers that were selected for inclusion on the basis of their abstracts were classified using an adjusted coding scheme with the elements:

1. Identification (e.g. year), including discipline of authors (e.g. natural sciences) and type of nanotechnology (e.g. applied to food),
2. Type of research (e.g. whether or not empirical),
3. Main theoretical approach (e.g. TAM),
4. Dependent variable (e.g. attitude),
5. Data source (e.g. individual consumers).

This coding scheme is based on the scheme of the review on societal response to previous novel technologies. Fine-tuning for the case of nanotechnology was based on accumulating insights from the first review. Therefore, the final search was done on 13 October, 2010.

Data analysis

Content analysis was applied to both reviews. Where appropriate, χ^2-tests were conducted to investigate associations between variables. In papers where multiple application areas, theoretical frameworks, dependent variables or data sources were mentioned, these were dealt with as independent observations in the χ^2-tests.

Results

Review 1: societal response to previous novel technologies

The search, presented in Table 1, resulted in 213[2] abstracts that were screened. Eighty-seven were excluded based on the rejection criteria applied to the abstracts. The excluded papers dealt with a great variety of other topics, see Fig. 1.

The full text of the 126 remaining papers was acquired from the Wageningen University and Research Centre Library (the host institution of the authors). Those not available were requested either through the interlibrary service or by requesting a copy from the corresponding author of the paper by e-mail. Of the full papers investigated, 11 were irrelevant to the research question as these did not discuss response to technology ($N = 3$), did not deal with response at all ($N = 6$), were written in French[3] ($N = 1$). One case was used in two papers by the same authors, in an almost identical context. To prevent overemphasis on this approach, the most recent one was excluded. Eight papers were not retrievable. The paper selection process is displayed in Fig. 1.

Description of the final set

In the final set of 107 papers, the number of papers increased from 1 in 1991 to 17 in 2008 and 19 in (the first 9 months of) 2009. Two-thirds of the included set was based on empirical data ($N = 83$). The majority of papers applied ($N = 52$) or adapted ($N = 44$) an existing theoretical approach, whereas a smaller number developed new theories or concepts ($N = 9$).

Most data were collected amongst inhabitants of European and Northern American countries, most frequently in the USA ($N = 26$) and the UK ($N = 11$). Asia ($N = 26$) was represented by Japan ($N = 7$), Hong Kong ($N = 6$), Taiwan ($N = 5$), China ($N = 3$), Korea ($N = 3$), Malaysia ($N = 1$) and Thailand ($N = 1$). Of the 26 papers from the

[2] The full list of these papers is available on request from corresponding author.

[3] This paper was in the included set because its abstract was in English.

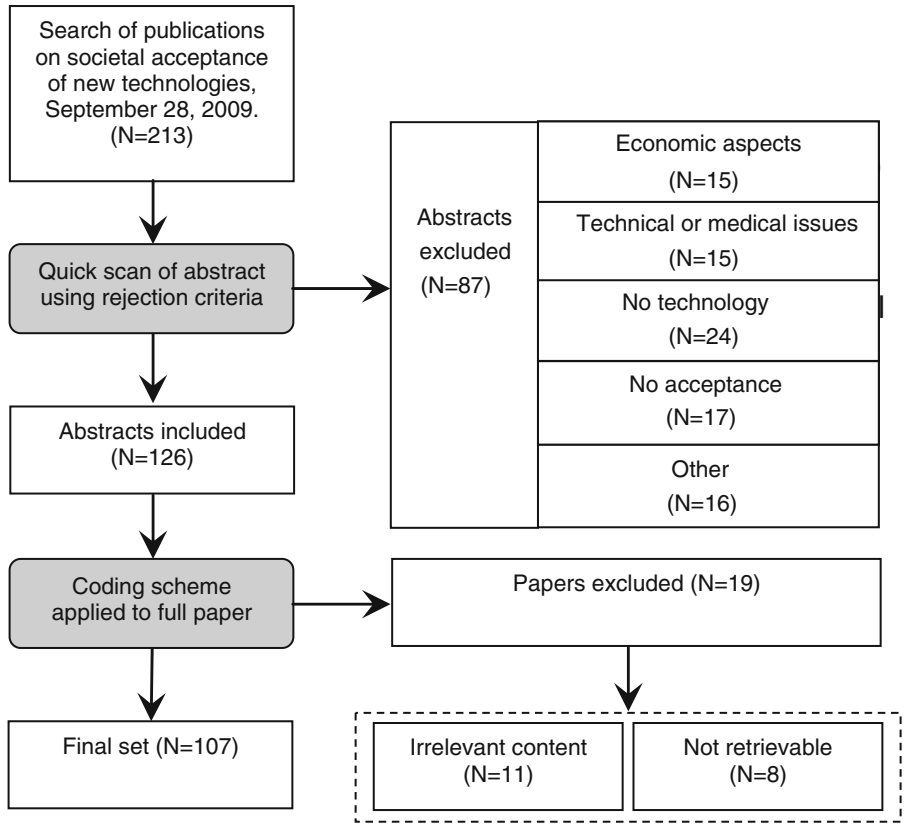

Fig. 1 Flowchart of systematic review on societal response to new technologies

Asian countries most studied information technology ($N = 16$), with the exceptions of 6 Japanese studies on nuclear energy, 3 studies on vaccination from China, Hong Kong, and Thailand and 1 Japanese study on multiple other technologies. The proportion of studies on information technology, compared to other technologies in the Asian countries, was significantly higher than in the western countries ($\chi^2(df = 1, N = 112) = 11.65; p < 0.01$).

Type of technology

Information technology has been the subject of study most frequently ($N = 39$), followed by biotechnology ($N = 25$), food technology ($N = 14$), nuclear energy ($N = 14$) and vaccination ($N = 8$). Nanotechnology, the most recent emerging technology, was studied in 4 of the 107 papers. The other technologies studied in the set were civil engineering, electromagnetic fields, phytoremediation, renewable energies and radio frequency identification (RFID) (all occurring only once). Listing all 272 authors in the dataset showed that the majority appears only once, and that 25 authors appear twice or more often. Of these 25 authors, four studied various technologies, combinations being information technology and food/biotechnology (Konana and Balasubramanian 2005; Rimal et al. 2005), information technology and health care technology (Katz and Rice 2009; Rice and Katz 2008) and electromagnetic fields and nanotechnology (Siegrist et al. 2003; Wiek et al. 2009). The other 21 authors published multiple times on the same technology.

Theoretical approaches

The TAM has been used most frequently ($N = 27$). The TAM, originally developed by Davis (1989), proposes that users' acceptance of a new technology is determined by their intention and attitude towards using the technology. Intention and attitude, in turn, are influenced by two factors, in particular, namely

perceived usefulness and perceived ease of use. Using the same rational actor assumption as TAM, the Theory of Planned Behaviour (TPB) ($N = 11$) points to perceived behavioural control (i.e. whether an individual thinks he can actually perform the behaviour) as a determinant of behaviour and behavioural intention, together with social norm (i.e. whether significant others are likely to support the behaviour) and attitude (i.e. the extent to which a person is positive or negative about engaging in the behaviour) (Ajzen 1991). End-user knowledge, a lack of which leads to scepticism towards technological innovation and science in general according to the so-called deficit model (Wynne 1991), was included in six papers.

The Health Belief Model ($N = 2$) and Protection Motivation Theory ($N = 2$) also adopt a rational actor model to individual behaviour. The Health Belief Model originated in social psychology and assumes that an individual will perform a health-related behaviour when he or she (a) feels that a negative health condition can be avoided, (b) expects that by taking the recommended action, this negative health condition will be avoided and (c) believes in his or her successful performance of the recommended behaviour. Protection Motivation Theory was developed to understand fear appeals and proposes that people protect themselves based on four factors: (a) the perceived severity of a threatening event, (b) the perceived probability of the event, (c) the efficacy of the recommended preventive behaviour and (d) the perceived self-efficacy.

The diffusion of innovations theory (present in three papers) was popularised by Rogers (1995), and studies societal adoption of innovations. Rogers' model of diffusion of innovations has identified five characteristics of innovations that present rational deliberations explaining the differences in adoption rates of various innovations. These are (a) relative advantage, i.e. delivering a benefit over preceding technologies, (b) compatibility, i.e. fitting in with values, experiences and needs of potential adopters, (c) complexity, i.e. level of ease of use, (d) trialability, i.e. the possibility to experiment with an innovation before actual adoption and (e) observability by others.

Constructs in the papers that are less dependent on the rational actor assumption are risk perception ($N = 22$), trust ($N = 17$) and benefit perception ($N = 10$). Risk and trust are studied in conjunction in five papers; risk and benefit perception are studied together in eight papers. The social amplification of risk framework ($N = 3$) states that when people have no direct personal experience with a certain risk, they rely on two communication networks, namely, the news media and informal personal networks. This framework was proposed by Kasperson et al. (1988) to explain why risk events with minor physical consequences can still cause strong societal concern. Social influences were studied in 11 papers. A considerable number of papers ($N = 72$) used yet other theoretical approaches. These approaches varied heavily (68 different approaches[4]). Forty-one papers used none of the approaches described above.

Table 3 presents the relationship between application area and theoretical approach used. TAM was exclusively applied in the field of information technology.

A cross table comparing theoretical approach with country of study showed that there is an association between the use of the rational actor assumption and country ($\chi^2(df = 1,\ N = 96) = 10.56;\ p < 0.01$). The rational actor assumption (underpinning TAM, TPB, prior knowledge) was applied more often in Asian countries than in Europe and the USA. Similarly, affective variables (such as perceptions of risk and benefit, trust, and social influences) were used more in Europe and the USA than in Asia.

When the papers using TAM were studied in more detail, it appeared that none of the 27 use TAM as their only theoretical approach. Seven combined the TAM with trust, 6 with social influence, 4 with risk, 2 with knowledge, 1 with cost and another 18 with various other constructs, such as consumer characteristics like innovativeness, and features of the retail environment. Risk and benefit perception have relatively frequently been used in the context of biotechnology and food technology.

Dependent variable

Various measures have been used for societal response, of which intention ($N = 37$) and attitude ($N = 30$) were used most frequently. Other dependent variables were risk perception ($N = 15$), use

[4] Overview available on request from the corresponding author.

($N = 9$), benefit perception ($N = 4$) and policy recommendations ($N = 3$).

There is an association between the four mostly used constructs and application area ($\chi^2(df = 9, N = 87) = 29.81$; $p < 0.001$); intention and attitude were used more often in information technology studies, whereas risk perception was used more often in biotechnology and nuclear technology papers (Table 4).

When the TAM or TPB were used as the theoretical framework, intention and attitude were measured as the dependent variable, whereas risk perception was never the dependent in studies using TAM or TPB (Table 5).

Table 3 Theoretical approach per application area

Theoretical approach	Application[a]				
	Information Technology	Food Technology	BioTechnology	Nuclear Technology	Total
TAM	27	0	0	0	27
Risk perception	4	7	6	4	21
Trust	7	5	5	1	18
TPB	9	2	2	0	13
Social influence	8	1	1	0	10
Benefit perception	2	6	6	1	15
Prior knowledge	3	3	1	0	7
Total	60	24	21	6	

[a] For reasons of robustness, only application areas and approaches described in a sufficient number of papers were analysed

Table 4 Dependent variable per application area

Dependent	Application[a]				
	Information Technology	Food Technology	Bio Technology	Nuclear Technology	Total
Intention	30	3	3	0	36
Attitude	15	3	6	5	29
Risk perception	1	3	6	4	14
Use	4	2	2	0	8
Total	50	11	17	9	

[a] Only application areas described in a sufficient number of papers were analysed for reasons of robustness

Table 5 Dependent variable per theoretical approach

Dependent	Approach							
	TAM[a]	RP[b]	Trust	TPB[c]	SI[d]	BP[e]	PK[f]	Total
Intention	22	7	7	10	7	4	2	59
Attitude	10	4	5	6	3	2	2	32
Risk perception	0	4	3	0	0	2	1	10
Use	2	2	1	2	2	1	1	11
Total	34	17	16	18	12	9	6	

[a] Technology Acceptance Model

[b] Risk perception

[c] Theory of Planned Behaviour

[d] Social influence

[e] Benefit perception

[f] Prior knowledge

Data source

The majority of papers collected data amongst individual consumers ($N = 75$), whereas the public more broadly was used in 22 cases. A minority of papers had retrieved information from documents ($N = 4$) or representatives of industry ($N = 3$). Amongst the other data sources were most frequently experts, for example, expressing views for other societal groups (e.g. adolescents) (Ford et al. 2009).

Discussion of societal response to previous novel technologies

The most influential theoretical approaches used to study societal response to novel technologies build on the rational actor assumption, with the TAM being used most frequently. The TAM has been extended with prior knowledge and cost as new explanatory variables. In addition, the present review showed the tendency to extend the "rational" TAM with more affective variables (e.g. trust, social influence and risk and benefit perceptions). This tendency may be an indication of the shifting view on the human psyche from a rational towards a more emotional paradigm in the social sciences. However, when affective determinants were used, a general framework was often lacking.

A wide range of approaches to the study of societal response to novel technologies have been described in the reviewed papers. The vast majority of studies questioned individual consumers to investigate societal response, and only few used other sources (e.g. policy makers), making the subject of study much more homogenous across the papers.

Review 2: societal response to nanotechnology

The final search term (see Table 2) resulted in 88[5] hits. After excluding 39 papers based on their abstracts and another 7 after reading the full text, the final set for content analysis contained 42 papers (see Fig. 2).

Description of the final set

The 42 papers were published from 2002 until 2010 with 11 papers in 2008. Over half of the papers ($N = 22$) reported empirical results against 20 having no empirical data. Most empirical papers were published in the last 3 years (see Fig. 3).

The papers appeared in 28 different journals. The Journal of Nanoparticle Research was the most frequently used outlet ($N = 10$), followed by Public Understanding of Science ($N = 3$), Health, Risk and Society ($N = 2$), Science Communication ($N = 2$) and Risk Analysis ($N = 2$). Apart from acknowledging the (US) National Science Foundation, most papers did not acknowledge a funding source or did acknowledge their own university or a teaching program, indicating that funding was mainly supplied by the host institutes of the researchers, and that external funding has not resulted in much output in scientific journals (yet).

The majority of papers ($N = 37$) discussed societal response to nanotechnology, in general, 2 were in the area of nanotechnology in food (Kuzma et al. 2008a; Siegrist et al. 2007), 1 in the military area (Altmann 2004), 1 in the workplace (Schulte and Salamanca-Buentello 2007) and 1 in animal production (Kuzma 2010). Most studies were conducted in western countries, with the USA as the most frequently present country ($N = 9$). Noteworthy is the absence of most Asian countries, except from single papers from Iran (Ghazinoory and Ghazinouri 2009) and Japan (Nakagawa et al. 2010). Judged by authors' affiliation as stated on the paper, the minority of author teams consisted exclusively of natural scientists ($N = 3$); 16 papers were written by social scientists, 12 by interdisciplinary researchers (e.g. Human, Environment and Technology in Schutz and Wiedemann 2008) and 4 by a mixed team of both natural and social scientists. The authors' disciplines of the remaining seven papers could not be determined. Nine out of 80 authors (co) authored multiple included papers.

Five of the 42 papers developed a new theory or concept (e.g. integrating multiple perspectives for oversight assessment of emerging technologies, Kuzma et al. 2008b), 3 adapted an existing theoretical approach, and 13 applied an existing theoretical approach. A large proportion of papers ($N = 16$) consisted of cross-sectional studies, whereas 11 were position papers and 11 were case studies.

[5] The full list of these papers is available on request from the corresponding author.

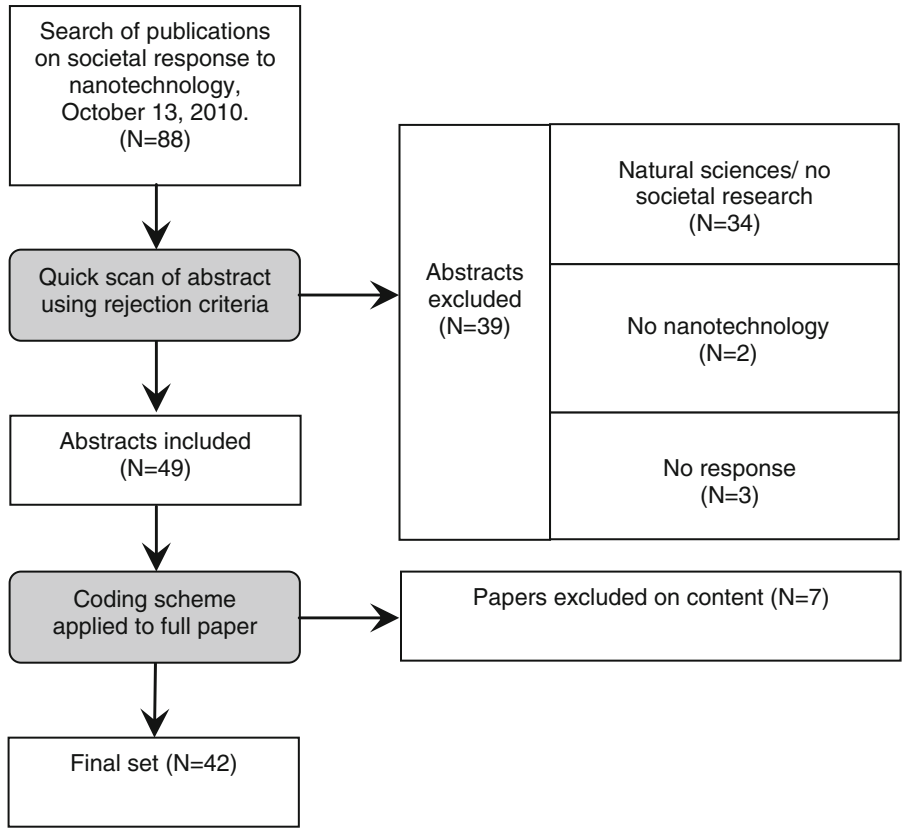

Fig. 2 Flowchart of systematic review on societal response to nanotechnology

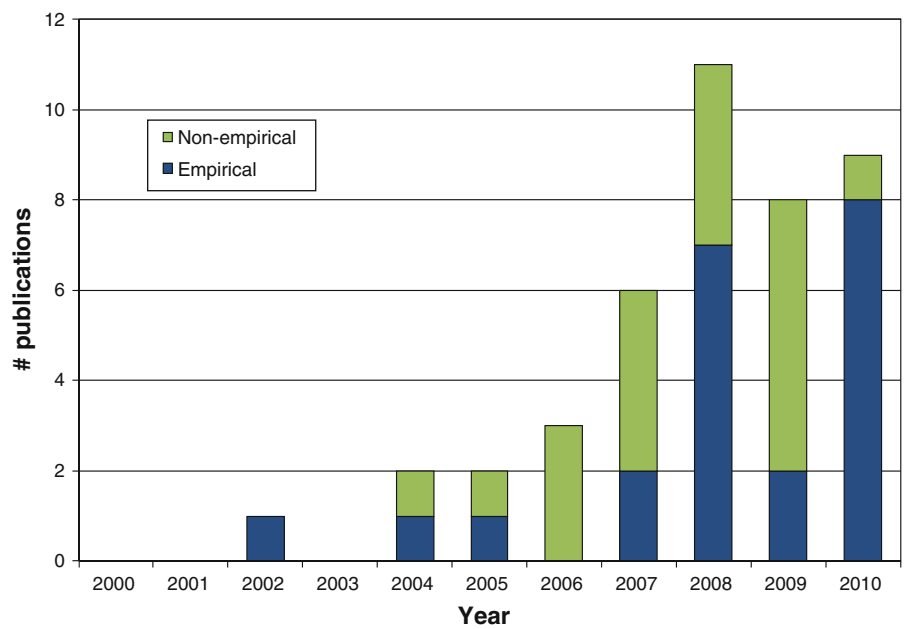

Fig. 3 Publication trend of nanotechnology response papers

Theoretical approaches

In contrast to the papers in the review on societal response to previous novel technologies, no clear-cut theoretical models (such as TAM) were used as the basis of research. Instead, various paradigms served as the starting point (see Table 6). Sixteen papers had an individual perspective in their theoretical approach. A large proportion of these individual-level papers investigated considerations outside the rational actor paradigm, such as emotion (Lee et al. 2005), affect (Siegrist et al. 2007), trust (Stebbing 2009), risk perception (Pidgeon and Rogers-Hayden 2007) and benefit perception (Schutz and Wiedemann 2008). Rational considerations studied were: knowledge (Lee et al. 2005), framing effects (Schutz and Wiedemann 2008) and cognitive barriers (Grinbaum 2006). Thirteen papers took a societal-level perspective, of which 2 discussed ethical aspects of nanotechnology (Schulte and Salamanca-Buentello 2007; Stebbing 2009), and 11 used other theoretical approaches, such as technology assessment (Burri and Bellucci 2008), public engagement (Katz et al. 2009) and socio-technical system analysis (Ghazinoory and Ghazinouri 2009). Seventeen out of 42 papers used none of previously developed theoretical approaches, but instead often discussed the need to "do something".

In contrast to many of the papers reported in review 1, risk perception ($N = 7$) and benefit perception ($N = 6$) were the most frequently reported proxy for response instead of intention. Other frequently mentioned dependent variables were policy ($N = 4$) and attitude ($N = 6$). Five studies did not report a dependent variable at all.

Table 6 Theoretical approaches in nanotechnology response research

	Number of papers[a]
Individual level	*16*
Rational considerations	3
Non-rational considerations	12
Other individual level	1
Societal level	*13*
Ethics	2
Other	11
Other level	*2*
None	*17*

[a] As many papers use multiple approaches, the numbers add up to more than 42

Discussion of societal response to nanotechnology

The results presented in this review suggest that in general, the study into societal response to nanotechnology is beginning to take off. The publication of papers directly aimed at nanotechnology and society has commenced in 2002, and their number has been growing rapidly since. The majority of empirical studies have been published in the last 3 years, which indicates that the field of societal nanotechnology response research is maturing. The variety in research paradigms is high and there is no omnipresent theoretical framework to predict response to nanotechnology. Thorough accounts of how the public will respond, based on a strong theoretical starting point, or truly collaborative appraisal shared between social and natural scientists appear to be rare to date. The most important outcome variable is not response itself but the perceptions of risk and benefit. This implies that the final step towards comprehensive study of the response to nanotechnology has not yet been taken.

General discussion and conclusion

This paper shows that rational actor models have played an important role in the study of societal response to technology, in particular in information technology and specific geographic regions (Asia). In contrast, response to biotechnology and nuclear technology has more often been investigated through risk perception and other affective determinants, in particular in Western Europe and the USA. The associations found between the use of the rational actor assumptions and country of study should be interpreted with care, however, as Asian countries were also better represented in information technology studies which are more often studied in the rational actor paradigm.

There is a tendency to extend rational actor-based models with affective variables. If this trend is to persist, then the relative importance of rational actor assumptions versus affective factors will become unravelled. Also, situations dominated by more deliberate reasoning frames could be identified, and

others by more affective reasoning. This would fit with the current view that human information processing takes place at two discrete levels (e.g. Chaiken and Trope 1999; Kahneman 2003), depending on situation and motivation. Mutual neglect of these parallel information processing modes (except for a few studies, e.g. Griffin et al. 1999; Trumbo 1999, 2002), together with the still largely separated views on humans as either rational or non-rational beings, shows that convergence in social science approaches to response to new technologies has a long way to go.

Societal response research into nanotechnology shows similarities to the research into biotechnology and nuclear technology. Nanotechnology response research builds on affective variables such as risk perception. There are some indications that public response to nanotechnology is taken up by the same research community as that involved in biotechnology. A comparison of the datasets of review 1 (previous novel technologies) and review 2 (nanotechnology) points out that some researchers involved in nanotechnology have previously studied biotechnology, whilst in our selection no authors studied both nanotechnology and information technology. However, our dataset was not constructed to answer this issue conclusively making any conclusion tentative, and a topic for future research.

When conducting these reviews, we noticed that it is often hard to compare the papers and thus aggregate the knowledge from social sciences. This is due to the large variety in constructs that have been studied, but also in differences of naming of only subtly distinct constructs, the paradigmatic differences between different social sciences and the creation of subcultures of social scientists associated with a specific application field. This scattered jargon within the social sciences themselves may become a serious barrier in the progress of the social sciences. This problem is not necessarily limited to the social sciences, as many scientific fields have gone through periods of diverging terminology. The challenge for the social sciences, and even more so for researchers of societal response to novel technologies, is to converge towards some shared principles.

To answer the question posed in the title of this paper; where information technology and life sciences seem to be converging for nanotechnology, the research into societal response to nanotechnology is not converging. As long as social scientists across domains fail to incorporate each other's findings, a robust evaluation of the societal impact of technology development cannot be given. Therefore, based on this review we call for serious effort in taking up the best parts from the rational actor models dominant in information technology, whilst integrating non-rational constructs from biotechnology research. The introduction of nanotechnology gives a unique opportunity that allows for convergence in the study of technology acceptance, as nanotechnology combines the approaches from information technology, biotechnology, cognitive science and medicine (Roco and Bainbridge 2002).

Acknowledgements This research was financially supported by Cefic-LRI (Long-range Research Initiative).

References

Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211

Altmann J (2004) Military uses of nanotechnology: perspectives and concerns. Secur Dialogue 35(1):61–79. doi:10.1177/0967010604042536

Bainbridge WS (2002) Public attitudes toward nanotechnology. J Nanopart Res 4(6):561–570

Burri RV, Bellucci S (2008) Public perception of nanotechnology. J Nanopart Res 10(3):387–391. doi:10.1007/s11051-007-9286-7

Chaiken S, Trope Y (1999) Dual-process theories in social psychology. Guilford, New York

Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q 133:319–339

Ford CA, English A, Davenport AF, Stinnett AJ (2009) Increasing adolescent vaccination: barriers and strategies in the context of policy, legal, and financial issues. J Adolesc Health 44(6):568–574. doi:10.1016/j.jadohealth.2008.11.015

Frewer LJ, Lassen J, Kettlitz B, Scholderer J, Beekman V, Berdal KG (2004) Societal aspects of genetically modified foods. Food Chem Toxicol 42(7):1181–1193

Ghazinoory S, Ghazinouri R (2009) Nanotechnology and sociopolitical modernity in developing countries: case study of Iran. Technol Econ Dev Econ 15(3):395–417. doi:10.3846/1392-8619.2009.15.395-417

Griffin RJ, Dunwoody S, Neuwirth K (1999) Proposed model of the relationship of risk information seeking and processing to the development of preventive behaviors. Environ Res A 80(2):S230–S245

Grinbaum A (2006) Cognitive barriers in perception of nanotechnology. J Law Med Ethics 34(4):689–694

Gupta N, Fischer ARH, Frewer LJ (2011) Socio-psychological determinants of public acceptance of technologies: a review. Public Underst Sci. doi:10.1177/0963662510392485

Huffman WE, Rousu M, Shogren JF, Tegene A (2004) Consumer's resistance to genetically modified foods: the role of information in an uncertain environment. J Agric Food Ind Organ 2(2):1–13

Jacobs A (2004) Sociological practitioners contributing to new product development: mapping the challenges. Sociol Res Online 9(4):28

Kahneman D (2003) A perspective on judgment and choice: mapping bounded rationality. Am Psychol 58(9):697–720

Kasperson RE, Renn O, Slovic P, Brown S, Emel J, Goble R, Ratick S (1988) The social amplification of risk: a conceptual framework. Risk Anal 8(2):177–187

Katz E, Rice RE (2009) Public views of mobile medical devices and services: a US national survey of consumer sentiments towards RFID healthcare technology. Int J Med Inform 78(2):104–114. doi:10.1016/j.ijmedinf.2008.06.001

Katz E, Solomon F, Mee W, Lovel R (2009) Evolving scientific research governance in Australia: a case study of engaging interested publics in nanotechnology research. Public Underst Sci 18(5):531–545. doi:10.1177/0963662507082016

Konana P, Balasubramanian S (2005) The social-economic-psychological model of technology adoption and usage: an application to online investing. Decis Support Syst 39(3):505–524. doi:10.1016/j.dss.2003.12.003

Kuzma J (2010) Nanotechnology in animal production: upstream assessment of applications. Livest Sci 130(1–3): 14–24. doi:10.1016/j.livsci.2010.02.006

Kuzma J, Paradise J, Ramachandran G, Kim JA, Kokotovich A, Wolf SM (2008a) An integrated approach to oversight assessment for emerging technologies. Risk Anal 28(5):1197–1219. doi:10.1111/j.1539-6924.2008.01086.x

Kuzma J, Romanchek J, Kokotovich A (2008b) Upstream oversight assessment for agrifood nanotechnology: a case studies approach. Risk Anal 28(4):1081–1098. doi:10.1111/j.1539-6924.2008.01071

Lee CJ, Scheufele DA, Lewenstein BV (2005) Public attitudes toward emerging technologies: examining the interactive effects of cognitions and affect on public attitudes toward nanotechnology. Sci Commun 27(2):240–267. doi:10.1177/1075547005281474

MacOubrie J (2006) Nanotechnology: public concerns, reasoning and trust in government. Public Underst Sci 15(2):221–241

Nakagawa Y, Shiroyama H, Kuroda K, Suzuki T (2010) Assessment of social implications of nanotechnologies in Japan: application of problem structuring method based on interview surveys and cognitive maps. Technol Forecast Soc Change 77(4):615–638. doi:10.1016/j.techfore.2009.11.002

O'Hara K, Morris R, Shadbolt N, Hitch GJ, Hall W, Beagrie N (2006) Memories for life: a review of the science and technology. J R Soc Interface 3(8):351–365. doi:10.1098/rsif.2006.0125

Pidgeon N, Rogers-Hayden T (2007) Opening up nanotechnology dialogue with the publics: risk communication or 'upstream engagement'? Health Risk Soc 9(2):191–210. doi:10.1080/13698570701306906

Rice RE, Katz JE (2008) Assessing new cell phone text and video services. Telecomm Policy 32(7):455–467. doi:10.1016/j.telpol.2008.05.005

Rimal AP, Moon W, Balasubramanian S (2005) Agro-biotechnology and organic food purchase in the United Kingdom. Br Food J 107(2):84–97. doi:10.1108/00070700510579162

Roco MC, Bainbridge WS (2002) Converging technologies for improving human performance: nanotechnology Biotechnology Information Technology and Cognitive Science. National Science Foundation, Arlington, VA

Roco MC, Bainbridge WS (2005) Societal implications of nanoscience and nanotechnology: maximizing human benefit. J Nanopart Res 7(1):1–13. doi:10.1007/s11051-004-2336-5

Rogers EM (1995) Diffusion of innovations, 4th edn. Free Press, New York

Ronteltap A, van Trijp JCM, Renes RJ, Frewer LJ (2007) Consumer acceptance of technology-based food innovations: lessons for the future of nutrigenomics. Appetite 49(1):1–17. doi:10.1016/j.appet.2007.02.002

Schenk MF, Fischer ARH, Frewer LJ, Gilissen LJWJ, Jacobsen E, Smulders MJM (2008) The influence of perceived benefits on acceptance of GM applications for allergy prevention. Health Risk Soc 10(3):263–282

Schulte PA, Salamanca-Buentello F (2007) Ethical and scientific issues of nanotechnology in the workplace. Environ Health Perspect 115(1):5–12. doi:10.1289/ehp.9456

Schutz H, Wiedemann PM (2008) Framing effects on risk perception of nanotechnology. Public Underst Sci 17(3): 369–379

Siegrist M (2010) Predicting the future: review of public perception studies of nanotechnology. Hum Ecol Risk Assess 16(4):837–846. doi:10.1080/10807039.2010.501255

Siegrist M, Earle TC, Gutscher H (2003) Test of a trust and confidence model in the applied context of electromagnetic field (EMF) risks. Risk Anal 23(4):705–716

Siegrist M, Cousin ME, Kastenholz H, Wiek A (2007) Public acceptance of nanotechnology foods and food packaging: the influence of affect and trust. Appetite 49(2):459–466. doi:10.1016/j.appet.2007.03.002

Slovic P (1987) Perception of risk. Science 236(4799):280–285

Stebbing M (2009) Avoiding the trust deficit: public engagement, values, the precautionary principle and the future of nanotechnology. J Bioethic Inq 6(1):37–48. doi:10.1007/s11673-009-9142-9

The Royal Society and The Royal Academy of Engineering (2004) Nanosciences and nanotechnologies: opportunities and uncertainties. Imperial College Press, London, p 111

Trumbo CW (1999) Heuristic-systematic information processing and risk judgment. Risk Anal 19(3):391–400

Trumbo CW (2002) Information processing and risk perception: an adaptation of the heuristic-systematic model. J Commun 52(2):367–381

Wiek A, Gasser L, Siegrist M (2009) Systemic scenarios of nanotechnology: sustainable governance of emerging technologies. Futures 41(5):284–300. doi:10.1016/j.futures.2008.11.016

Wynne B (1991) Knowledges in context. Sci Technol Hum Val 16(1):111–121