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Anticipating the perceived risk of nanotechnologies

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Understanding emerging trends in public perceptions of nanomaterials is critically important for those who regulate risks. A number of surveys have explored public perceptions of their risks and benefits. In this paper we meta-analyse these surveys to assess the extent to which the following four hypotheses derived from previous studies of new technologies might be said to be valid for nanotechnologies: risk aversion will prevail over benefit appreciation; an increase in knowledge will not result in reduced aversion to risks; judgements will be malleable and subject to persuasion given risk-centric information; and contextual, psychometric and attitudinal predictors of perceived risk from prior studies can help anticipate future perceptions of nanotechnologies. We find that half the public has at least some familiarity with nanotechnology, and those who perceive greater benefits outnumber those who perceive greater risks by 3 to 1. However, a large minority of those surveyed (44%) is unsure, suggesting that risk judgements are highly malleable. Nanotechnology risk perceptions also appear to contradict some long-standing findings. In particular, unfamiliarity with nanotechnology is, contrary to expectations, not strongly associated with risk aversion and reduced 'knowledge deficits' are correlated with positive perceptions in this early and controversy-free period. Psychometric variables, trust and affect continue to drive risk perceptions in this new context, although the influence of both trust and affect is mediated, even reversed, by demographic and cultural variables. Given the potential malleability of perceptions, novel methods for understanding future public responses to nanotechnologies will need to be developed.

There has been unprecedented interest in anticipating how the public will respond to nanotechnology, including expectations of widespread risk aversion[1], given the possible health risks associated with nanomaterials[2]. Many in the nanotechnology community worry that public protest could follow in a manner akin to that which has shadowed biotechnology in the UK and Europe or chemical and nuclear technologies in the United States[3,4]. Those who explore public perceptions of risk[5] have traditionally studied social and psychological responses to risks, contamination events[6] and technological disasters[7] once they have occurred in order to forensically unearth the drivers of controversy including its correlates and amplifying agents[8,9]. The objective of such work has been to understand a number of phenomena: the logic of risk perceptions including their social and management contexts (for example, processes of risk regulation and risk communication); mental models or 'lay judgements' of the perceived causes and consequences of risk exposure; and attitudinal or affective variables that predict patterns of aversion to or tolerance of technological risks[10]. The correction of factually incorrect risk perceptions per se has not been the primary concern (although some of this has occurred[11]). Conversely, what is now termed 'upstream research'[12] with emerging nanotechnologies involves monitoring perceptions before any widely accepted empirical evidence of potential heath risks can be inferred, or any hint of controversy can be detected. It also means measuring perceptions of nanotechnologies well before they exist as a definable entity or class of objects in the publics' imaginations or before new regulatory contexts are in place[13]. Perception is critical[14] for a number of reasons: because human behaviour is derivative of what we believe or perceive to be true; because perceptions and biases are not easily amenable to change with new knowledge[15,16]; and because risk perceptions are said to be, at least in part, the result of social and psychological factors and not a 'knowledge deficit' about risks per se[17].

In previous social studies of risk, a cluster of factors was found to drive perceptions. These include specific qualities or 'psychometric ratings' attributed by the perceiver to the risk object, the demographic attributes and attitudinal dispositions of the perceiver, and the perceived quality of the risk communication, management and remediation contexts associated with risk events. Specifically, perceived risk is high when the new technology is rated by different publics as dreaded, involuntarily imposed, unfamiliar or unknown, invisible[18], or carrying a negative affective valence[19,20]. Perceived risk is also high if the technology (for example, nuclear power or genetically modified organisms) is seen as beyond one's personal control, involuntarily imposed and/or inequitably distributed[18]. In their aggregate, these ratings having produced characterizations or 'mental or cognitive models' of perceived risk that are basic to the processing, uptake or rejection of new [risk] information[21]. More recent work has focused on the power of 'affect' in perceived risk; specifically, the negative or positive valences rapidly and preconsciously associated with a risk object are highly and efficiently predictive of perceived risk, perhaps as much or more so than all other variables[22,23].

Second, in the US context, when the perceiver is male, white, high-income earning, and well educated, he will perceive the risks of most hazardous technologies as much lower than will those in all other demographic groups including white women, and all nonwhite men and women[24,25]. Third, high perceived risk is also attributed to attitudinal variables including those who regard themselves as vulnerable and subject to injustice[26,27], as wary of science and technology[28,29], skeptical of political authority or expertise[30,31] and as dose insensitive (that is, they see risk as a function of 'any exposure', however small)[32]. Fourth, risk

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Table 1 | Questions amenable to meta-analysis from 22 risk perception surveys from 2004 to 2009.

Journal article	n	Format	Population	Date of survey	Shared dataset	Familiarity/ knowledge	Risk vs benefit judgements	Risk judgements vs familiarity
Scheufele (2008)[68]	1,015/29,193	TS	US/EU	Feb–June 2007 / Nov–Dec 2005				
Smiley-Smith (2008)[69]	1,014	TS	US	6 Aug	1		×	
Kahan (2009)[42]	1,850	WS	US	6 Dec	2	×	×	
Kahan (2008)[70]	1,850	WS	US	6 Dec	2	×*	×*	
Kahan (2007)[49]	1,850	WS	US	6 Dec	2	×*	×*	×*
Kahan, Sovic (2008)[55]	1,600	WS	US	June–Aug 2007		×	×	
Siegrist (2008)[60]	337	MS	Swiss	Not given				
Hart (2007)[51]	1,014	TS	US	7 Aug		×*	×*	×*
Siegrist (2007)[56]	375	MS	Swiss	2006–2007		×*		
Hart (2006)[50]	1,014	TS	US	6 Aug	1	×*	×*	×*
Fujita (2006)[73]	1,011	IN	Japan	Nov–Dec 2004		×	×*	
Priest (2006)[71]	1,200/2,000	TS	US/CAN	5 Jan	3	×*	×*	
Einsiedel (2005)[76]	1,200/2,000	TS	US/CAN	5 Jan	3	×	×	
Macoubrie (2006)[72]	152	GS	US	2005–2006		×*	×	
Currall (2006)[74]	4,542/503	WS/TS	US	4 Jun			×	
Sheetz (2005)[65]	978	QU	US	2005		×*		
Cobb (2005)[57]	1,536	TS	US	4 Mar	4		×	
Lee (2005)[54]	706	TS	US	Autumn 2004	5		×	
Scheufele (2005)[67]	706	TS	US	Autumn 2004	5	×*	×	
Gaskell (2005)[75]	850/15,000	TS/IN	US/EU	Dec 2002–Feb 2003/Sep–Oct 2002			×*	
Cobb (2004)[40]	1,536	TS	US	4 Mar	4	×*	×*	
Royal Society (2004)[66]	1,005	GS	UK	2003		×*	×	

TS, telephone survey; WS, web survey; MS, mail survey; IN, interview; GS, group survey; QU, questionnaire.
* Papers that provided complete results that were amenable to the meta-analysis done in this study.
Similarities in question sets across 22 papers allowed for a meta-analysis of three clusters of questions (on familiarity/knowledge with nanotechnology, risk versus benefit judgements, and risk judgements versus familiarity). Ten papers provided complete results for familiarity/knowledge question, seven provided complete data for risk versus benefit judgement questions, and three provided data for risk judgements versus familiarity, with missing data provided by the authors of these works upon request. Other papers included here are those used in the deductive analyses of additional findings in Fig. 4.

judgements are highly sensitive to negative information[33,34]. Thus, the stigmatization[23,35] of specific technologies or risks tends to occur when risk management has been badly handled (for example, unrealistic promises of 'no risk' or 'failure to accept responsibility in the face of a risk event'[36]), when the perceiver's distrust of risk managers and regulatory agencies is high[28,37], when risk management practices are not transparent, and when a risk event (for example, severe acute respiratory syndrome (SARS), a gas leak or a contamination event) is seen to 'signal' worse events yet to come[38].

Given earlier risk research, it is reasonable to hypothesize as follows:

- Public response to nanotechnology would parallel other new and unknown technologies such as biotechnology and thus early evidence of risk aversion would prevail.
- An increase in knowledge will not result in reduced aversion to risks.
- Judgements about nanotechnology will be highly malleable and subject to persuasion given risk-centric information.
- Contextual, psychometric and attitudinal predictors of perceived risk from earlier studies can anticipate future perceptions of nanotechnologies.

In this paper we synthesize and meta-analyse, where possible, findings from all search-available surveys of public perceptions of nanotechnology carried out in the past decade in the industrialized world, primarily in Europe and North America. We assess the extent to which these hypotheses might be rejected, confirmed or modified for emerging nanotechnologies. Table 1 lists the datasets from which we drew, and details the question sets where it was defensible to combine data and or calculate a more precise effect size due to semantic similarity in the type of questions and wording of scales. Further question sets where defensible quantitative comparison of data was possible follow below and provide a more accurate and credible overview of findings than can be provided by any one study or in non-quantitative review papers. Aspects of the datasets that could not be quantified, especially those pertaining to contextual and attitudinal factors, are analysed deductively in the light of past work on risk perception[39].

Familiarity, malleability and judgement uncertainty

Public familiarity with nanotechnologies across 11 eligible studies in North America, Europe and Japan is very low, as shown in Fig. 1. When the samples were pooled, more than 51% (s.e. = 4%) of all participants who were asked about their familiarity with this new class of technology reported knowing 'nothing at all', although variation across individual studies was large (25–71%). Among five studies that probed more deeply into levels of familiarity, the remainder of the population split into an average 30% who reported knowing 'just a little', and 20% claiming to know 'some' or 'a lot'. When US studies alone were considered, 47% of pooled participants self-reported 'no' or zero knowledge. No clear trend is evident of increased familiarity or knowledge over the period of time the surveys were performed.

The low level of familiarity invokes the two long-standing findings in the field noted above. The first has concluded that risk objects that are 'new', comparatively 'unknown to science' and 'not observable' (that is, not easily detected by smell, taste, touch or sight) are characteristically judged as highly risky[7,18]. Extrapolating to nanotechnologies, which can equally be characterized as new, with properties and behaviours as yet comparatively unknown to science, and materially intangible or invisible, one would expect high risk ratings or at least a propensity towards

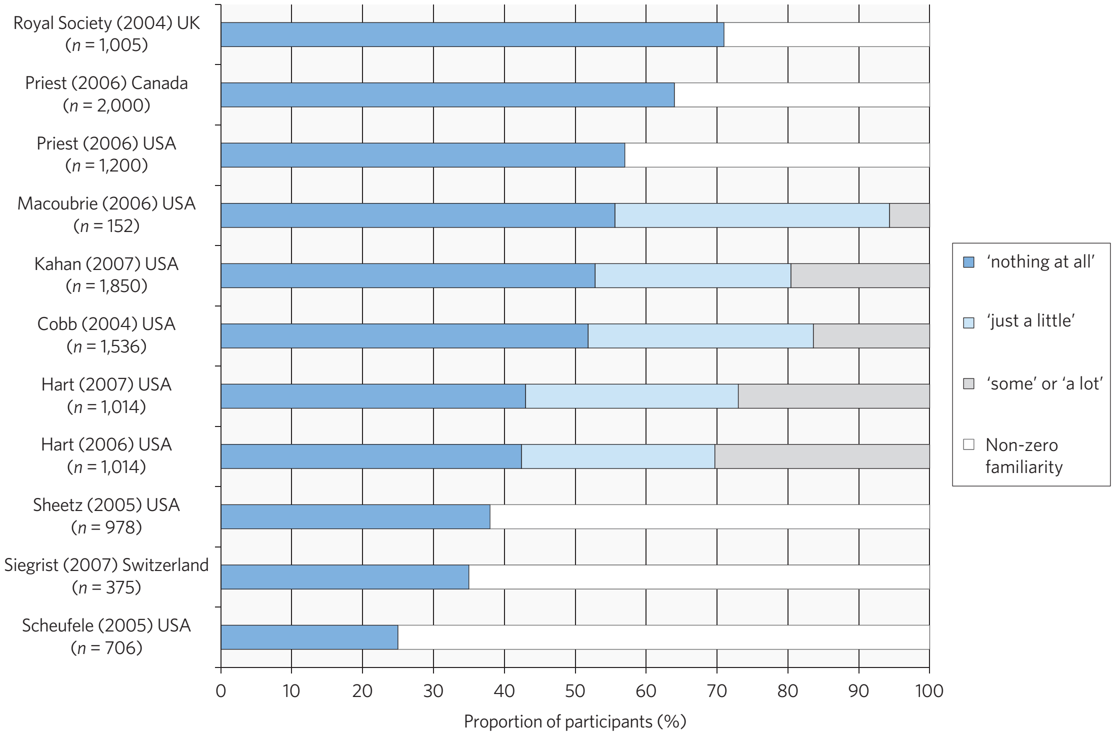

Figure 1 | Self-reported familiarity with nanotechnologies. Approximately half of all survey participants (51% for pooled data, standard error (s.e.) = 4%; 49% for unweighted average, s.e. = 3.7%) had zero familiarity, or had heard 'nothing at all', about nanotechnologies. The number reduces slightly (47%) when only US surveys are considered (s.e. = 3.5%)[40,49–51,65,67,71,72]. Of the 11 studies that asked familiarity questions (for example, 'How much have you heard about nanotechnology?')[40,49–51,56,65–67,71,72], five reported participants' level of understanding beyond a simple binary classification ('a lot', 'some', 'just a little')[40,49–51,72]. In the remaining six studies[56,65–67,71] a breakdown of the participants' level of familiarity beyond 'nothing at all' is not reported, and is represented here as 'non-zero familiarity'.

'default' risk aversion. However, as seen in Fig. 2, the aggregated evidence so far finds that study respondents either believe that benefits outweigh risks or equal the risks, or they exhibit strong resistance to offering risk or benefit judgements of any kind.

In the nine surveys that asked a specific question on whether judgements of benefit exceed risks and vice versa, all nine surveys saw benefits as outweighing risks—an overall pattern widely reported in the survey literature to date[40,41]. A third of the pooled respondents felt that benefits may exceed risks—approximately 3.5 times as many as those who felt that risks will exceed benefits. Strikingly, an average of 44% of respondents (11–53% across studies) were 'not sure' of the risks or benefits of these technologies. This may indicate healthy judgement conservatism, but it may also suggest that the widely reported benefit centrism may be overstated. Rather, this judgement conservatism may point to considerable potential malleability of risk and benefit judgements, whereby judgements could move in either direction—a possibility explored by Kahan and colleagues[42]—or in response to any risk information that may yet emerge.

A second widely held claim in the perceived risk literature holds that lay persons judge many risks as higher than experts, not because of a 'knowledge deficit' per se, but because of the very different basis with which lay persons view and characterize risk when compared to experts (for example, lay distrust of expertise may be more important than estimates of mortality or morbidity[17]). However, in one study of comparisons of lay versus expert judgements of nanotechnology risks, the expert community seems to be more risk averse than the public with regard to pollution and 'new health problems'[43]. Unlike the nanotechnology research analysed here, in most earlier (non-upstream) studies the risk objects under consideration have been at the centre of controversy (nuclear power, genetically modified foods, pesticide or chemical risks, mad cow disease, climate change and so on), and nested in regulatory failures and risk-amplifying media coverage[9,36]. This might well explain the high base rate of perceived risk among public groups when compared to experts[44]. It may also explain the skeptical relationship between risk perception and knowledge, in which information provided may be received as suspiciously persuasive and thus enhances risk aversion[34]. In studies that examine public attitudes more broadly, some have argued that rejection of the 'knowledge deficit' hypothesis is overstated[45], and that there is a weak but persistent link between knowledge and positive attitudes toward technologies. However, trust is often an intervening variable and it depends on the subgroup (pro-industry versus pro-environment) to which one belongs[46]. Others find that the relationship between perceived risk and knowledge is 'chaotic'[47] suggesting a strong role for context. A more recent meta-analysis of science literacy as a correlate of non-upstream attitudes towards technologies (nuclear power, genetically modified organisms, stem cell research and so on) is comparatively definitive[48]. It found across 193 publicly available datasets that general knowledge of science has a weak but stable and positive effect on attitudes toward science and technology in their aggregate (0.08 for Cohen's D weighted regression coefficient), an effect that is weakened when general knowledge is compared to specific technologies, is non-significant in some cases (nuclear power and genetic medicine), and negative in other relationships (for example, environmental science knowledge and attitudes towards genetically modified foods).

This implies a need to examine domain-specific knowledge with domain-specific attitudes, an examination that is consistent with this meta-analysis. A full assessment of the benefit–knowledge relationship in the nanotechnology case is not possible yet.

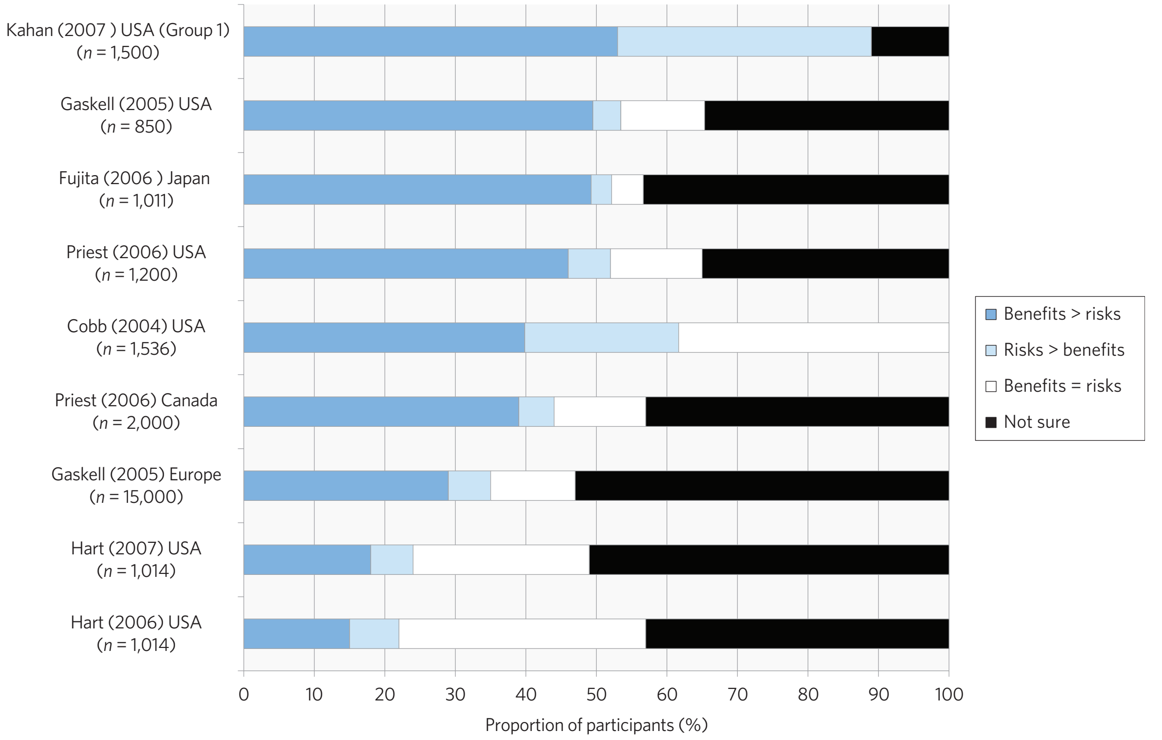

Figure 2 | Public perceptions of the relative risks versus benefits of nanotechnology. Survey participants were not provided with any information about the risks and benefits of nanotechnologies. Of those willing to make a judgement, more participants judged that benefits would exceed risks than the reverse in all nine surveys[40,49–51,71,73,75], and the remainder was split 2:1 between judging that benefits are equal to risks, or risks exceed benefits. A large portion of participants were unwilling to make a risk versus benefit judgement with a pooled average of 44% (s.e. = 3.4%), and an unweighted average of 39% (s.e. = 4.6%) stating they were 'not sure' about whether risks would exceed benefits, or benefits would equal or exceed risks.

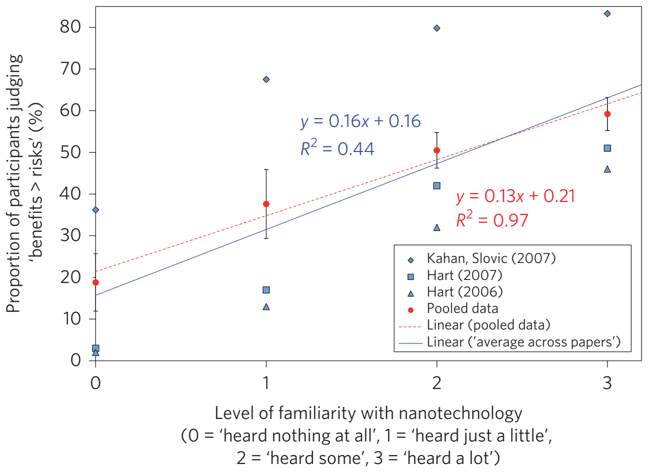

Figure 3 | Proportion of participants judging that benefits will exceed risks given their previous familiarity with nanotechnology. As the level of familiarity with nanotechnology increases, the proportion of participants judging that benefits will exceed risks increases significantly. The points in blue represent the proportion of respondents who judge 'benefits exceed risks' for each level of familiarity in each of three surveys[49–51]. A linear regression (blue trend line) shows that the proportion of respondents judging 'benefits exceed risks' increased by nearly 16% for each step increase in familiarity ($R^2 = 0.44$, $P = 0.02$). The points in red represent the pooled data, where data from each familiarity group is aggregated to obtain an average weighted by sample size across all three papers. A linear regression (red dashed trend line) shows a similar increase of 13% in proportion of respondents judging 'benefits exceed risks' with each step increase in familiarity ($R^2 = 0.97$, $P = 0.014$).

However, we can examine the 'familiarity hypothesis': the belief that benefit judgements will increase in conjunction with familiarity[40]. Familiarity might serve as a proxy for knowledge insofar as awareness belies some knowledge. Aggregation and regression of data across the three nanotechnology risk perception studies carried out in the United States that allowed for such a comparison indicate that familiarity does breed consent (Fig. 3)[49–51]. A strong and significant relationship exists between respondents' self-assessed level of familiarity with nanotechnology and the belief that the benefits of nanotechnologies exceed their risks. Regression indicates a steep increase in likelihood of judging benefits as exceeding risks with each step increase in familiarity (an ∼13% increase per step), although most of this increase occurs in the movement from 'no familiarity' to 'heard a little'. This study also finds a stronger relationship between knowledge and risk–benefit associations. Cohen's *D* measure comparing the 'no familiarity' group with those that have 'a little', 'some' and 'a lot' of familiarity shows effects sizes of 0.91, 1.08 and 1.52, respectively—all considered large effects[52]. Despite such a strong relationship it is not clear whether the positive-benefit effect associated with greater familiarity reflects this early stage of technological development, or a *de facto* function of technological optimism whereby those who seek out knowledge about nanotechnologies are positively predisposed to new technologies and their benefits[28].

Optimism, affect and untested variables

Expectations that benefit judgements will further increase with knowledge or familiarity should be treated with caution. A recent study of nanotechnology judgements and cultural biases found no support for the familiarity hypothesis[42]. Previous risk research on controversial technologies, such as biotechnology, indicates that a nanotechnology-related risk event may change the playing field, and so convert a positive knowledge–attitude relationship to a

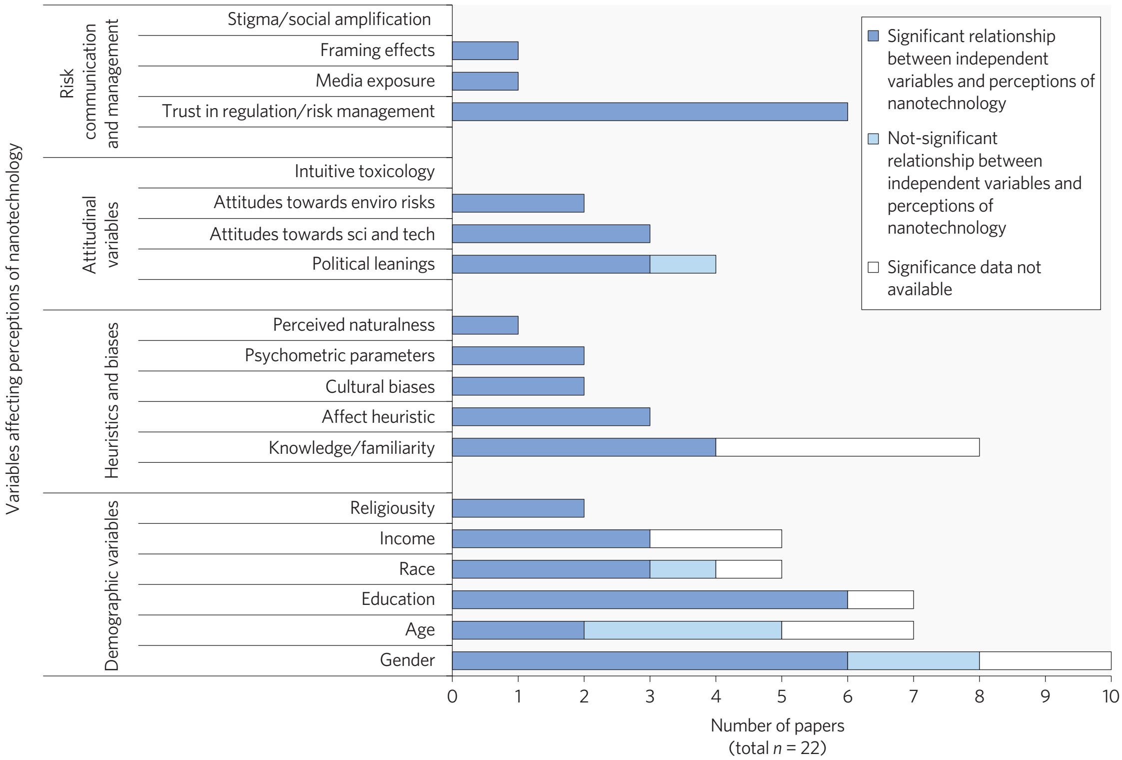

Figure 4 | Number of papers exploring the role of risk communication and management variables, attitudinal variables, heuristics and biases, and demographic variables in influencing risk judgements. Several demographic attributes, as well as knowledge/familiarity, trust, political leanings and attitudes towards science and technology received the most attention in the literature across categories[40,42,49–51,54–57,60,66,68–71,76]. Some demographic attributes showed conflicting results, with several papers finding a significant relationship between the attribute and risk judgement, and others finding them not significant (for example, gender, age).

negative one[53]. Assumption of benefit centrism may also under-estimate the countervailing power of known or as yet untested predictors of risk. Figure 4 demonstrates that research to date remains focused on demographic variables. Gender and race predict high perceived risk in the nanotechnology case[49], but further work on how these intersect with other attitudinal factors is needed. Trust is the only non-demographic attitudinal factor more widely examined (and was found to be a significant predictor of risk judgements in all studies; Fig. 4), including trust of the regulatory agencies responsible for risk management. Affect has in part replaced more conventional psychometric variables. Affect ratings (negative versus positive valences associated with nanotechnology) were highly significant in one study when compared to knowledge, which was not significant[54]. A second study found perceptions to be largely 'affect driven', although more informed persons relied less on affect, with cultural worldview predispositions mediating affect and polarizing risk judgements[49,55]. Only a modicum of attention has been paid to proven predictors of risk perceptions including known psychometric ratings (dread, perceived controllability of nanotechnologies, and so on), yet evidence for their importance remains strong. Siegrist and colleagues[56] found the psychometric factor 'dread risk' (comprising worry, control, voluntariness of exposure and so on) as the most important predictor of nanotechnology risks in a principle component analysis, whereas trust was marginally significant and ethical justifications not significant. Together, these factors accounted for 87% of the variance of perceived risk, thereby asserting the ongoing importance of psychometric dimensions in combination with other factors (trust and ethics in this case). Attitudes toward science and technology are significant predictors of benefit in three papers[40,54,56] (an important finding to the extent that judgements of benefit may well be a proxy for positive attitudes towards science more broadly)[28].

Surprisingly little attention has been paid to many other key variables in risk research, including the effects of framing by print and television media[57,58], activists and health and safety advocates, and intuitions about toxicology (dose insensitivity or worries about carcinogenicity generally); frames that control for benefit–risk information and tradeoffs are also largely untested. This is a particularly fruitful area of research as it might help us understand, by mimicking in survey design, frames that capture the potential social contexts of emerging risks (for example, comparing frames that emphasize positive social climates and the support or not of respected civic and activist organizations). Given that a very large portion of people (44% noted above) have reserved judgement, it is all the more important to understand how perceptions are modulated by the application domain and risk-specific information as was true in the biotechnology case[59].

Scholars now need to understand how application domains with markedly different benefit–risk profiles are likely to influence perceptions of emerging nanotechnologies. Key here is whether risk aversion in one application domain is likely to carry over to all nanotechnologies, or will it be limited to the specific application or the nanomaterial in question? Surprisingly, only a few studies to date have probed this in any detail[56], including a study of applications in the food industry and a cross-national deliberative study of energy versus health applications in which domain was meaningful[56,59]. In short, the very malleability of risk judgements here and now calls for intentional (and logically defended) framings in survey design and better use of intercepting independent variables and contextual descriptions, as a flawed but best proxy available for anticipating the perceived risk of nanotechnologies.

Conclusions

Like biotechnology before it, the scientific community sees nanotechnology as protean, with myriad applications in multiple domains. There is also awareness among scientists and technocrats that publics, particularly in the 'risk societies' of the industrialized world are unlikely to unquestioningly embrace the technology. The first round of applications, what Renn and Roco[61] call 'passive nanostructures', are primarily in the realm of material applications, where the focus is likely to be on environmental and health considerations, a familiar domain of risk research. Surveys conducted over the past decade provide an empirical basis for examining emerging attitudes towards risks and benefits of these applications. Overall participants across survey studies regard nanotechnology as resulting in more benefits than risks, and familiarity with this new technology does correspond to positive evaluations of its applications. Theoretically, the generally moderate attitudes towards nanotechnology that accompany the current upstream moment provide an ideal opportunity for better understandings of benefits and not just risks. However, benefit optimism should be tempered because a large proportion of sampled publics have suspended judgement, which suggests that judgements are malleable as yet. History has demonstrated that attempts to engineer risk perceptions with education campaigns may backfire if the benefits are oversold or the risks downplayed.

Surveys of lay perspectives on nanotechnologies have emerged as critical tools for anticipating the trajectory of risk judgements, but few have exploited some of the more long-standing findings in the literature, including established theoretical propositions about the context of risk management or the psychometric properties of risk objects. The field likely needs to mature[62] towards testing known factors in this upstream context including intuitions about exposure, stigmatizing versus attenuating messages, the effects of media framings on nanotechnology judgements, the effects of describing nano-enabled objects (such as sunscreen or more energy-efficient window coatings) and then providing tutorial material on different types of risks associated with nanomaterials, and variations in benefit distribution. Given the potential malleability of judgements, and sensitivity of such judgements to contextual and constructive framings[63], such investigations will be crucial to understanding future responses. More broadly, as applications move as predicted towards more complex domains where bio-, information and nanotechnologies converge, the nature of the risks involved will move beyond the immediate concerns related to toxicity and enter into contentious moral and ethical terrains. As technologies converge, so will the risk debates. Seen this way, controversy might be inevitable, and perhaps the only way for societies to debate a technology with enormous and unforeseen social consequences. Social science methods and tools will need to evolve and indeed are evolving[62] to meet the challenge.

Methods

A meta-analysis was carried out on 18 independent surveys conducted over the past decade aimed at characterizing the public response to nanotechnologies (Table 1). The surveys summarized here were included in 22 papers focusing on risk perceptions published between 2004 and 2009. Surveys included a mix of methods including six telephone surveys, three mail surveys, two group surveys, two web surveys, one based on interviews, one using both a telephone survey and an interview, and another using both a web survey and a telephone survey. Although a majority of the studies were carried out in North America (11 in the United States, one in Canada) the analysis includes findings from surveys done in Europe ($n = 5$) and Japan ($n = 1$). We recognize that views across nation states may differ, and so show results for aggregated cross-national samples as well as for the United States alone.

Meta-analysis is a method used for combining quantitative information on research hypotheses from various sources, particularly observational studies and clinical trials. Meta-analyses provide several advantages over literature reviews[39], including avoidance of relying on the results of a single study or a non-quantitative review, the ability to aggregate data from studies carried out with diverse samples and methods, and the ability to detect, reject and combine effect sizes. Perceptions of risks and benefits of nanotechnology are emerging and so are likely to be labile and potentially malleable. Thus, variation in survey methods such as those described above could have a large impact on risk–benefit perceptions across study samples. Consequently, results that are consistent over studies done with different samples may reflect more stable findings, while those that show larger variation across studies might point to greater malleability of perceptions in risks and benefits.

Meta-analysis of survey data is relatively uncommon because survey data can be more heterogeneous than data derived from observational work[64]. In this work it was possible to defensibly combine data on three questions across subsets of surveys shown in Table 1. These were related to the questions on public familiarity with nanotechnology, on perceptions of the relative risks and benefits of nanotechnology, and on the role of knowledge in determining risk–benefit judgements. The ability to meta-analyse each of these data domains also depends on the semantic proximity of questions or items in the first place, so questions were carefully scrutinized for the defensibility of their inclusion. For example, most items on knowledge or familiarity asked respondents how much they had heard about nanotechnology, using the response scale 'heard nothing at all', 'heard just a little', 'heard some' and 'heard a lot'. Slight variations included 'have you heard of the term nanotechnology' and 'how much did you know about nanotechnology before participating [in this survey]?' Measures of knowledge/familiarity in these data are all based on 'self-reported' levels of knowledge. Although four studies do use knowledge tests[40,65–67], differences in scales and data availability rendered these unsuitable to meta-analysis. Those studies meta-analysed for comparisons on risk versus benefit findings asked very similar questions about whether 'benefits outweighed risks', were 'about equal' or whether 'risks outweighed benefits'. Figure 2 notes the one study by Kahan *et al.*[49] that did not ask respondents if risks 'equalled' benefits; wording in this study also varied from the others in asking if 'the benefits of nanotechnology will slightly outweigh the risks', 'greatly outweigh the risks' and vice versa.

Data were also presented using both weighted and unweighted approaches. In a weighted approach, metrics from different surveys are combined to produce metrics for a pooled sample. Pooling the results weights the importance of each survey by its sample size. In the unweighted approach each survey (as opposed to each instance from the sample) carries the same weight. Many surveys did ask questions on attributes of the observer, attributes of the risk object and processes of risk management. However, heterogeneity of questions meant that it was not possible to summarize responses into a common metric for quantitative comparison across surveys. Consequently, survey findings related to demographic and attitudinal variables are synthesized in a statistically descriptive manner only.

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Author contributions

T.S. and M.K. conceived and designed the meta-analysis. C.B. and M.K. analysed the data. T.S. wrote the paper, with M.K. and C.B. providing input on original drafts and revisions. B.H.H. and J.C. provided key materials and summaries of studies, and all authors discussed the results and commented on the manuscript.

Additional information

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CORRIGENDUM

Anticipating the perceived risk of nanotechnologies

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In the version of this Article originally published, the data from ref. 50 used in the meta-analysis and plotted in Fig. 2 were incorrect because these data were subsequently corrected in ref. 51. This mistake does not change any of the conclusions of the paper. An error also occurred in plotting the data from ref. 40 in Fig. 2, but the correct data were used in the rest of the paper. Figure 2 (including caption) and the first two sentences of the paragraph beginning "In the nine surveys" on page 754 of this Article have been amended accordingly in the HTML and PDF versions of the Article.