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Framing effects on risk perception of nanotechnology

Holger Schütz and Peter M. Wiedemann

How do people judge nanotechnology risks that are completely unfamiliar to them? Drawing on results of previous studies on framing and risk perception, two hypotheses about potential influences on nanotechnology risk perception were examined in an experimental study: 1) Risk perception of nanotechnology is influenced by its benefit perception. 2) Risk perception of nanotechnology is influenced by the context in which nanotechnology is embedded, specifically by the characteristics of the enterprises that profit from nanotechnology: large multinational enterprises versus small and medium-sized enterprises. In contrast to findings for other new technologies, e.g. biotechnology, the different types of benefit did not affect risk perceptions in our study. However, we found that characterizing the enterprises as large multinational versus small or medium-sized leads to differences in risk perception. One can speculate that when personal knowledge about a technology is lacking, people use more familiar aspects from the social context as cues for their risk evaluation.

Keywords: risk perception, nanotechnology, benefits, framing, social characteristics.

1. Introduction

Nanotechnology is widely recognized as one of the key technologies of the twenty-first century (Paschen et al., 2004; EU, 2004). Nanotechnology stretches across the entire spectrum of science and technology—with research and applications in physics, chemistry, engineering and electronics, as well as medicine. For example, nanotechnology provides the basis:

for ever smaller data storage devices while at the same time increasing memory capacity;
for highly efficient filters for wastewater treatment;
for photovoltaic windows;
for new materials allowing the automotive industry to produce ultra light engines and car body panels; and
for artificial joints whose nano surface coatings can be tolerated better by the human body (BMBF, 2004).

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The discussion of risks, however, is closely tied to the discussion of opportunities. Prominent critics—among them Bill Joy and Michael Crichton—warn of the potential risks associated with nanotechnology. In the year 2000, Bill Joy received public attention for his horror vision published in the magazine *Wired* where he envisions self-replicating nanorobots that, after having transformed all living organisms into nanosubstances, will leave behind a broad trail of destruction in the form of "gray goo." Michael Crichton drew up a gloomy scenario in his science-fiction thriller *Prey*. Nanorobots, designed by the military, escape from the laboratory to unite in swarms and attack humans.

In Europe, the political debate about the risk potentials of nanotechnology started in 2003. It was initiated in particular by Greenpeace (Arnall, 2003), the British Demos group (Demos, 2004), and the ETC group (ETC, 2003)—a non-governmental organization that previously has been successful in its fight against genetic engineering. There is growing concern among the scientists and supporters that nanotechnology could provide a target for intense debates about environmental and ethical consequences and dangers—analogous to those on biotechnology.

The Nanoforum, in cooperation with the European Commission, recently conducted an online survey to determine attitudes towards various aspects of nanoscience and nanotechnology development (Malsch and Oud, 2004). The survey revealed that a majority of the respondents (75 percent) believe that health, safety, and environmental risks should be integrated early into research. Furthermore, 75 percent are convinced that Europe should take account of the societal impact of nanotechnology from an early stage and that more communication and dialogue is needed.

This raises the question of risk perception: do the critical voices affect public response? Or, in other words: how does the public think about the risks of nanotechnology?

The predominant framework for studying risk perception has been the "psychometric paradigm" (see Slovic et al., 1980; Slovic, 1992) which argues that risk perception (in contrast to expert risk assessments) can be explained by a number of "qualitative characteristics," such as voluntariness of risk, its controllability, knowledge about the risk, dread associated with risk, and so on. Recently, however, a trend to more diverse methodologies can be observed, among them qualitative studies (e.g. Smith et al., 2006) and experimental designs (Corbett and Durfee, 2004).

This paper reports an experimental study, in which risk perception is studied with regard to a specific aspect: how do variations in the framing of risk issues influence risk perceptions of an emerging technology that is still largely unknown to the public?

2. Research on the public perception of nanotechnology

Research on risk perception of nanotechnology is at its very beginning. The few studies available so far on this issue are (with one exception) all surveys, looking at the public perception of the risks and benefits of nanotechnology or at knowledge about nanotechnology. These surveys reveal, not surprisingly, that the public's knowledge about nanotechnology is quite low. For instance, in 2004 a representative US phone survey found that about 80 percent of the respondents had heard "little" or "nothing" about nanotechnology (Cobb and Macoubrie, 2004). Another US telephone survey yielded a similar result (Scheufele and Lewenstein, 2005), as did a representative survey in Germany (Komm Passion, 2004).

Despite the admittedly low levels of knowledge about nanotechnology, the survey results also indicate that public perception of nanotechnology is more positive than negative. In the United States, for instance, Bainbridge (2002) conducted an Internet survey ($N = 3909$), indicating that only 9 percent of the participants agreed with the statement: "Our most powerful

21st-century technologies—robotics, genetic engineering, and nanotechnology—are threatening to make humans an endangered species."

The phone survey by Cobb and Macoubrie (2004) found that about 40 percent of the respondents thought that nanotechnology would produce more benefits than risks, 38 percent considered risks and benefits to be about equal, and only 22 percent said risks would outweigh the benefits. This study also revealed a number of interesting associations between the perception of nanotechnology and the respondents' views of science and their feelings towards nanotechnology. It turned out that the more positive the respondents' thoughts about science, the more they tended to see the benefits of nanotechnology outweighing the risks. Also, a majority of the respondents (70 percent) felt "very" or "somewhat" hopeful about nanotechnology, and only a minority (20 percent) expressed worry. Interestingly, about 60 percent of the respondents had "not much trust" in the ability or willingness of business leaders of the nanotechnology industry to minimize risks to humans.

Although a study by Gaskell et al. (2005) suggests that Europeans are more skeptical about the potential benefits of nanotechnology than people in the United States are, surveys in Britain (BMRB, 2004) and Germany (Komm Passion, 2004) find that the public sees little risk in nanotechnology.

Of course, one has to be careful in drawing too strong conclusions from the few available studies on public perception of nanotechnology. In addition, at least some studies may suffer from methodological limitations, such as low response rates or questionable representativeness of sampling in a Web survey. Bearing these caveats in mind, one can summarize the results of these studies in saying that, in general, they paint a favorable picture of the public perception of nanotechnology: in the eyes of the public the benefits outweigh the risks. But what determines these perceptions? The low level of the public's knowledge about nanotechnology suggests that they are not based on facts. Rather, one can speculate that feelings about nanotechnology and, indeed, more general attitudes towards science and technology determine these perceptions.

This speculation is supported by the results of a regression analysis that Cobb and Macoubrie (2004) performed in their above-mentioned study. Risk versus benefit ratings were regressed on 14 variables which included socio-demographic aspects (e.g. gender, age) and several attitudinal and knowledge related items. In this analysis "hope" and "worry"—together with the view of science—were the strongest predictors for perceptions of risks versus benefits, while other variables such as knowledge or "trust in business leaders" or socio-demographic factors such as gender or age were of minor importance.

An experimental study by Cobb (2005) analyzed how risk judgments and emotions about nanotechnology are influenced by how this technology is framed. He showed—among others—that characterizing nanotechnology as associated with health risks or with multiple economic and environmental risks resulted in a higher proportion of respondents who agreed with the statement "that risks will outweigh the benefits." However, when nanotechnology was framed negatively without mentioning specific risks he found no effect. Conversely, framing nanotechnology in terms of (multiple) benefits resulted in a larger proportion of respondents agreeing with "benefits will outweigh the risks."

3. Hypotheses

Two hypotheses are tested in this experiment. Both are derived from research on framing effects in behavioral decision-making which have been shown in numerous studies (see Kühberger, 1998 or Levin et al., 1998 for reviews). Tversky and Kahneman (1981: 453) defined a decision frame as "the decision-maker's conception of acts, outcomes and contingencies associated with a particular choice. The frame that a decision-maker adopts is controlled partly by the formulation of the problem and partly by the norms, habits, and personal characteristics of the decision maker." However, framing is not limited to the classical problem of describing options for decision-making in terms of loss and gain (Tversky and Kahneman, 1981; McNeil et al., 1982), but is also effective in elucidating the different "emotional coloring" of risk problems (Johnson and Tversky, 1983; Sandman et al., 1993). In this more general sense framing refers to the specific problem perspective that is induced through the description of the problem.

Hypothesis 1: Risk perception of nanotechnology is influenced by its benefit perception

We expect that providing information about different types of nanotechnology benefits will influence risk perception. Specifically we expect that applications of nanotechnology that provide medical or environmental benefits will receive lower risk judgments than applications for which the benefits are defined purely by economics.

Surveys on risk perception have observed an inverse relationship between risk and benefit perception, that is the higher the perceived benefits the lower the perceived risk and vice versa (e.g. Alhakami and Slovic, 1994; Fischhoff et al., 1978; Harding and Eiser, 1984). Moreover, experimental studies found that manipulating information about the benefits of a technology can even change its risk perception and vice versa (Finucane et al., 2000). For the field of biotechnology, a number of studies have shown that risk and benefit perception differ for "red" biotechnology (dealing with animals, e.g. animal cloning) and "green" biotechnology (dealing with plants, e.g. introduced pesticide resistance) (Gaskell et al., 2003; Savadori et al., 2004; Sjöberg, 2004). Results from Gaskell et al. (2004) suggest that the public's rejection of green biotechnology might be due to the low benefits that the public sees for this technology. Characterizing nanotechnology in terms of different types of benefits is an example of what Cobb (2005) has referred to as *issue framing*.

Hypothesis 2: Risk perception of nanotechnology is influenced by the social context in which nanotechnology is embedded

In previous experiments we and our colleagues have shown that identical risk information can provoke different risk judgments, depending on the "emotional coloring" of the social context in which the risk event is embedded (Spangenberg, 2003; Wiedemann et al., 2003). In these experiments, two versions of a risk story have been constructed that describe an objectively identical damage event. One version is meant to evoke outrage, while the other version to evoke leniency. On average, respondents in the outrage condition yielded (statistically significant) higher risk ratings than the respondents in the leniency condition. The "social context" information used to provoke outrage or leniency was related to characteristics of the parties (i.e. the actors) responsible for the risk situation. For instance—in the case of outrage—being a large multinational enterprise not caring about the worries of those affected by the risk, versus—in the case of leniency—being a small family business listening to the concerns of the people. We expect that the social characteristics of the enterprises involved in the development of nanotechnology will influence risk perception. If these characteristics are given a negative connotation, for instance as described above, this will amplify risk perception. If the connotation is positive, risk perceptions will be attenuated.

This type of framing is different from the *issue framing* used in hypothesis 1. In this case it is the information about the social context of nanotechnology which is changed, and not the information about the issue itself. We therefore refer to this type of framing as *context framing*.

4. Method

Study design

A 3 × 2 factorial design was used for this experiment. The first factor addresses the benefits of nanotechnology: 1) health benefits, 2) economic benefits, and 3) environmental benefits. The second factor varies the characteristics of the enterprises that benefit from nanotechnology: 1) large multinational enterprises, and 2) small and medium-sized enterprises.

Sample

The experiment was conducted with an ad hoc sample of students from the University of Innsbruck (Austria) and staff from the Center of Natural Hazard Management (AlpS) in Innsbruck. A total of $N = 194$ respondents participated in the experiment (female: 79 percent, male: 21 percent). Median age is 21 years (range: 19–60). The highest educational attainment of the participants was: university-entrance diploma (Matura): 87 percent, university degree: 13 percent. The experiment was carried out in March 2005 and took place in the seminar rooms of the University of Innsbruck and at the Center of Natural Hazard Management Innsbruck.

Materials

Six different short written descriptions of nanotechnology served as experimental stimuli. These comprised a basic text (given to all participants) and a combination of text modules for each variation of the two factors.

First, each participant received a basic text that gave a brief, factual introduction to nanotechnology:

> Nanotechnology is defined as technology that deals with dimensions on the order of one-billionth of a meter. In contrast, the thickness of a human hair is about 80,000 nanometers. Nanotechnology is focussed on creating and applying materials at a nanoscale dimension, i.e. at the scale of one to ten atoms in diameter. At the same time, the tools needed for being able to directly access and manipulate single atoms and molecules are being developed.

Subsequently, each participant received one of the six different combinations of text modules representing the 3 × 2 variations of the experimental factors. Participants were randomly assigned to the experimental conditions. Table 1 presents the text modules "benefits" and "characteristics of the enterprise."

After reading the text, the participants had to assess the likelihood of six risk scenarios (see Table 2). The scenarios were taken from the political discussion about possible risks of nanotechnology (cf. van Est et al., 2004). These scenarios address health and environmental hazards (scenarios A and B), "science-fiction" risks (scenarios C, D, E) and unknown risk potentials (scenario F). For assessing the probability of the scenarios, a 100-point rating scale with endpoints labeled "cannot happen" (0 percent probability) and "will happen" (100 percent probability) was given to the participants.

Table 1. Text modules used in the experiment

Experimental factor	Text modules
Benefits	"Health benefits" Nano-products are increasingly being used in medicine. It is estimated that by 2010 almost half of all pharmaceutical products will be based on nanotechnology. There are especially high hopes for the fight against cancer. "Economic benefits" Today, nanoparticles can already be found in sun lotion, cosmetics, textiles, tennis-rackets and -balls, computer displays, disinfectants, and bandages. This is, however, certainly just the beginning and economists expect the global market for nanotech products to rise to 900 million dollars in 2005. "Environmental benefits" Nanotechnology will enable the development of new materials, which will be of benefit to the environment and help to conserve energy.
Characteristics of the enterprise	"Multinational enterprise" Nanotechnology is primarily only a promising R&D technology for the large multinational companies, e.g. General Electric, IBM and Dupont. It will make the large multinational companies even more powerful. "Small and medium-sized enterprises" (SME) Nanotechnology offers especially for small and medium-sized companies an opportunity to enter the market and to establish themselves in competition against the large multinational companies.

Table 2. Risk scenarios

Scenario A	If materials that are normally harmless are adapted to superfine nanoparticles, they will become toxic and harmful to people
Scenario B	Nanoparticles will be distributed in the environment and substantially contribute to environmental damage
Scenario C	Nanorobots—invisibly tiny robots—will get out of control and threaten the human race
Scenario D	Nanosystems will integrate into living organisms, and will lead to the demise of the human race
Scenario E	Nanotechnology will result in dangerous hybrids—part human, part machine
Scenario F	Nanotechnology can lead to as yet unknown risks that can harm humans and the environment

5. Results

Figure 1 shows the probability assessments for the six risk scenarios. In this box plot, the middle 50 percent of the distribution (from the 25th percentile to 75th percentile) are shown as a box, while the vertical lines delineated by cross lines at the ends (the "whiskers") show the distance from the end of the box to the largest and smallest observed values that are less than 1.5 box lengths from either end of the box. The dots and asterisks denote individual judgments that lie outside of this interval (outliers and extreme values). The solid horizontal line inside the box is the median value. The variability in the assessments is conspicuous, both within and between scenarios. The average probability assessments are highest for the scenario "unknown risks," and lowest for the three "science-fiction" scenarios, with the health and environmental risk scenarios situated in between.

It is clear from Figure 1 that the distribution of the probability assessments for the risk scenarios is quite skewed. To further investigate this, non-parametric tests (Kruskall–Wallis and Mann–Whitney U) were used for the analyses of the experimental effects. For each risk scenario a separate test was conducted.

Figure 2 shows the probability assessments of the scenarios for the three types of nanotechnology benefits (factor 1: *issue framing*). It reveals noticeable differences between the probability assessments for scenarios A, B and F with regard to the three types of nan-

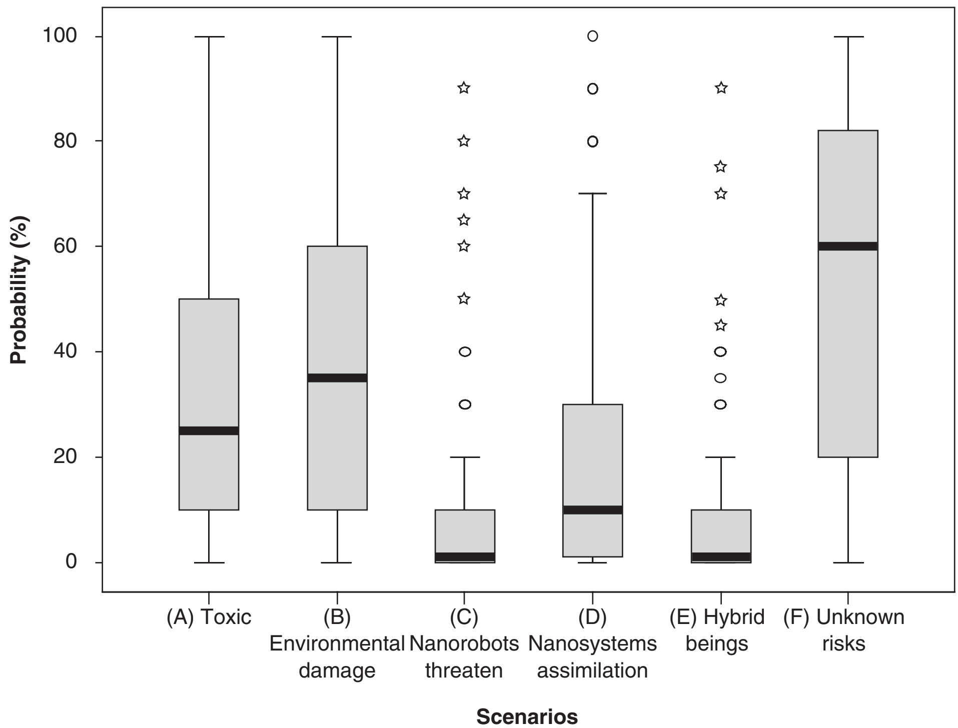

Figure 1. Box plot of the probability assessments for the six scenarios (scale: 0% to 100%).

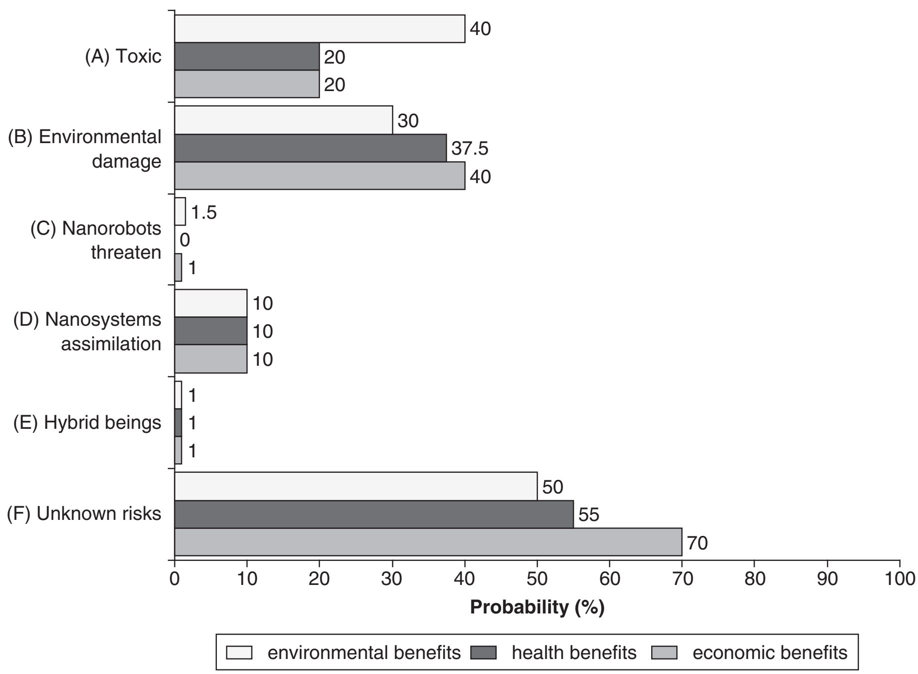

Figure 2. Median probability assessments for the factor "benefits."

Table 3. Effects of benefit of nanotechnology on the probability assessments of the risk scenarios (Kruskall–Wallis test)

Scenario	χ^2	df	*p*
(A) Toxic	2.7017	2	0.259
(B) Environmental damage	0.4853	2	0.785
(C) Nanorobots threaten	0.7314	2	0.694
(D) Nanosystems assimilation	0.1517	2	0.927
(E) Hybrid beings	0.0125	2	0.994
(F) Unknown risks	5.4789	2	0.065

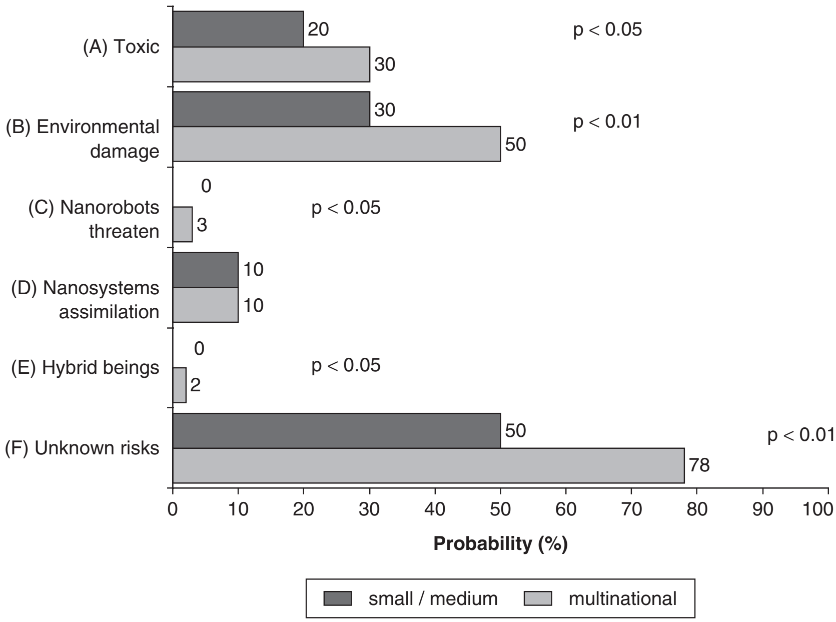

Figure 3. Median probability assessments for the factor "characteristics of the enterprise."

otechnology benefits. However, these differences are not statistically significant (see Table 3), although at least for scenarios B and F the order of the (median) probability assessments for the three types of nanotechnology benefits corresponds to the order that was expected in hypothesis 1. Nevertheless, it is clear from these data that the first hypothesis—the risk judgments depend on the type of benefit associated with nanotechnology—is not supported.

In contrast, factor 2 (*context framing*) yields statistically significant effects for five of the six scenarios (see Figure 3). And for three of these five significant results, the size of the effects is considerable. The differences between the characterization of the enterprise as multinational versus small or medium-sized are in the range of 10 percent to almost 30 percent. Table 4 gives the details of the statistical analysis.

Obviously, the characteristics of the enterprise benefiting from nanotechnology appear to affect the plausibility of risk scenarios. This result supports the second hypothesis. Risk judgments (in terms of plausibility of risk scenarios) are influenced by the social context in which nanotechnology is embedded. If small or medium-sized enterprises are portrayed to be the beneficiaries of nanotechnology, they receive lower probability assessments for five of the six risk scenarios.

Table 4. Effects of characteristics of the enterprises on the probability assessments of the risk scenarios (Mann-Whitney U test)

Scenario	Mann–Whitney U	*p*
(A) Toxic	3805.0	0.021
(B) Environmental damage	3456.5	0.001
(C) Nanorobots threaten	3903.0	0.042
(D) Nanosystems assimilation	4013.5	0.095
(E) Hybrid beings	3810.5	0.021
(F) Unknown risks	3514.5	0.002

6. Discussion

This experimental study investigates the effect of different types of framing on risk perception of nanotechnology. Different from most risk perception surveys, which typically ask for direct ratings of perceived risk, this study operationalizes risk perception in terms of probability assessments of given risk scenarios. This way of measurement was chosen, because the generally low level of public knowledge about nanotechnology at the present time renders the usefulness and logical sense of directly asking for risk judgments questionable.

The six different risk scenarios given to the participants receive quite different probability assessments. The highest assessments were given for the scenario F "unknown risks." Naturally, unknown risks can never be ruled out, but the high scores given for this scenario are striking and speak for negative expectations. However, if unknown risks are objectified—in terms of risks for human health (scenario A) or the environment (scenario B)—the respective scenarios receive much lower probability assessments. In addition, the probability assessments become very low if scenarios are to be assessed which portray developments of nanotechnology that belong—quite apparently—to the realm of science fiction.

As well as the general perceptions of nanotechnology risks, two specific hypotheses were investigated in this study. The first hypothesis, which proposed an effect based on the type of benefits that nanotechnology provides (health, environmental, and economic) on probability assessments of the scenarios, is not supported by the data. In contrast to findings for other new technologies, e.g. biotechnology, in our study the different types of benefit did not affect risk perceptions. Of course, this is not to say that benefits do not play a role for the perception of nanotechnology. In fact, the experimental study by Cobb (2005) found a statistically significant effect of *adding* benefit information to an objective description of nanotechnology on the risk–benefit evaluation.

The second hypothesis proposed an effect of *context framing*, namely that the social context in which nanotechnology is embedded influences risk perception. Specifically, the effect of characterizing the enterprises that benefit from nanotechnology as large multinational versus small or medium-sized, was expected to lead to differences in perceived risk. This hypothesis is supported by the data. In the experiment, participants given the "large multinational enterprises" condition assessed the probability of five of the six scenarios much higher than participants given the "small or medium-sized enterprises" condition did. In a different context we have described this type of influence as "story information" (Wiedemann et al., 2003), as it does not address the risk per se but the characteristics of actors who are involved in the risk generating process—either as being responsible for the risk or as being a "victim" of the risk. The social characteristics of these actors (e.g. size of an enterprise) can influence risk perceptions and ultimately risk judgments, although these characteristics do not have any direct relationship to the risk.

It can be speculated that such risk stories are engraved in the collective memory (Toumey, 2004), so that they would be available as yardsticks for evaluation (in the sense of Hsee, 2000). This would explain why social characteristics of enterprises—though factually irrelevant—have such an impact on risk perception.

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Authors

Peter Wiedemann, Ph.D., is the director of the program group MUT (Humans, Environment and Technology) at the Research Center Juelich, Germany. His research focuses on bridging the gap between risk perception research and risk communication on the one side and risk analysis and management on the other side. He is currently performing research in comparative risk assessment, uncertainty analysis, and evidence assessment to provide a basis of sound science for the application of the precautionary principle. **Correspondence**: Research Center Jülich, Program Group MUT, 52425 Jülich, Germany; e-mail: P.Wiedemann@fz-juelich.de

Holger Schütz is a senior researcher at the program group MUT. His research interests center on risk perception and risk communication.