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Great deeds or great risks? Scientists' social representations of nanotechnology

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Abstract

Nanotechnologies are becoming a larger presence in everyday life, and are viewed by governments and economic actors as a key area for development. The theory of social representations suggests that specialist views eventually disseminate to shape representations among the public (e.g. Bauer and Gaskell 2008). Yet nanotechnologies remain relatively little known to the general public (Satterfield et al. 2009). The media emphasize potential benefits, while potential risks get less attention (e.g. Friedman and Egolf 2011). The literature has not yet addressed whether representations by a well-informed population (scientists) are indeed structured in terms of the risk-benefit polarity that dominates research framing to date. We attempted a systematic assessment of how background knowledge about nanotechnology may influence experts' perception. Study 1 delivered the first demonstration derived from a qualitative analysis confirming the existence of a polarized representation of nanotechnologies, contrasting opportunity (medical, economic and technological) and risk. Interestingly risk was distinguished at two levels: that associated with nanomaterial characteristics (toxicity, reactivity) and at the larger scale of impact (health, environment, legislation). Does this polarity indicate a 'yes, but' logic (nanotechnology carries opportunity but also risk), or two clusters of specialists (sensitive respectively to opportunity or to risk)? Study 2 surveyed a larger sample of experts who self-described their scientific background and role viz. nanotechnology. Role had no influence. Specialists consensually viewed that nanotechnology represents opportunity, but depending on scientific background they did not agree to the same extent that nanotechnology also constitutes a risk. Participants with a physics and chemistry background tended to represent nanotechnologies predominantly in terms of opportunities and not in terms of inherent risks or impacts. In contrast, toxicologists, life and social scientists appeared to explicitly incorporate both benefits and risks in their representation of this new technology. Environmental scientists were a more diverse group, divided between the two patterns of representation.

Keywords: nanotechnology; nanomaterials; risk perception; scientists; experts; social representations.

Introduction: As nanotechnologies develop, do societal representations follow?

Apprehension in response to products based in groundbreaking scientific innovations is often a typical reaction of a public towards new and unfamiliar objects (Moscovici, 2001; Marcu et al. 2014). When doubts and debate around a given issue are observed amongst scientists themselves, they can be interpreted as part of the scientific process of knowledge production in which things are stated, contradicted and then reformulated. Our focus in this article is to explore societal debate about nanotechnology through the lens of the representations that nanoscientists share about their own work object. How do the scientists involved in development, testing, and/or applications of nanomaterials, and in current regulatory debate, integrate the risks and benefits they perceive to be part of nanotechnology into their informed position on the matter?

Nanoscience is the study of phenomena and manipulation of materials at an atomic, molecular and macromolecular level. At this scale, material properties differ significantly from those of larger scales (Royal Society & The Royal Academy of Engineering 2004), thus opening the way for a new generation of technology-based products (Joint Economic Committee 2007). Nanotechnology and the production of engineered nanomaterials already have had a major impact on e.g. electronics, telecommunication, construction, food technology, medical technologies, drug development, consumer sanitary care products, as well as environmental technologies, new agriculture, water purification systems and (renewable) energy production (Savolainen et al. 2013). In parallel with this development, the usage of products containing engineered nanoparticles stimulates significant concerns about possible unintended health or environmental effects (Royal Society & Royal Academy of Engineering 2004).

The excitement around this whole new area of research and economic development has provoked substantial public and private investment in R&D. Between 1993 and 2003, worldwide investments in nanotechnology research grew from $430 million to about $3 billion (Roco 2003) – corresponding in (non-adjusted) Euro to an increase in investments from approximately €332 million to about €2,1 billion. Since then the volume of activity has continued to increase. In the first decade of the 21st century, the United States alone invested more than $14 billion (about €11 billion) in the National Nanotechnology Initiative (Pidgeon, Harthorn, and Satterfield 2011). In the Europe of Horizon 2020, nanotechnology is labeled one of the key enabling technologies that can bolster Europe's competitiveness and its ability to provide the innovative goods and services essential for meeting global challenges; ensuring the safe and sustainable development and application of nanotechnologies in this way becomes a major European objective (Savolainen et al. 2013) justifying a large European R&D program. Thus, H2020-NMP[1] will attribute budgets of €232 million (about $300 million) in 2014 and €152 million (about $196 million) in 2015. The economy of products underpinned by nanotechnology is forecast to grow in Europe from a volume of 200 billion € (258 million $) in 2009 to 2 trillion € (2.58 trillion $) by 2015[2].

In parallel, scientists, regulators, civil society and industry seek agreement on a definition of 'nanomaterials' that will foster safety through enabling the correct application of notification, registration or authorization schemes (cf. e.g. Schneider

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[1] H2020-NMP-2014-2015, "H2020 Calls", European Comission, http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/master_calls.html#h2020-nmp-2014-2015 (accessed May 19, 2014)

[2] "Ireland's Nanotechnology Commercialisation Framework 2010 – 2014", Forfás, http://www.forfas.ie/media/forfas310810-nanotech_commercialisation_framework_2010-2014.pdf, cited in European Commission (2012).

2013). The 2011 European Commission Recommendation[3] defines 'nanomaterial' as '*a natural, incidental or manufactured material containing particles […] where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %.* […]'. The Commission states that while harmonization is sought, 'sector specific solutions' may nonetheless be necessary; the definition comes under review in 2014 (European Commission 2012).

Societal perceptions have come into view during this process of scientific and economic development (Shapira, Youtie, and Porter 2010). In some cases interest in public perceptions reflects concern by some scientists, industrial proponents and territorial economic actors that the 'fledgling industry' may spark the same polemics as have biotechnologies – e.g. genetically modified organisms (GMOs) or stem cells technology (Pidgeon, Harthorn, and Satterfield 2011). The assessment of how the public associates risks and benefits to a new technology is indeed a central feature of its acceptability (Slovic 2000). Societal views may also be recognized as an essential component in the governance of the innovation. The '21st century Nanotechnology R&D Act' (Law n° 108-153) enacted by the U.S. Congress in 2003 states that societal concerns must be identified through 'public input and outreach to be integrated (…) by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate'[4]. In the

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[3] Commission Recommandation 2011/696/EU, OJ L 275, 20.10.2011, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:275:0038:0040:EN:PDF

[4] US Public Law n° 108-153, Section 2 (10), par. D, http://www.gpo.gov/fdsys/pkg/PLAW-108publ153/html/PLAW-108publ153.htm

UK, noting that nanoscience and technologies attracted rapidly increasing interest and investment from the public and private sector worldwide, Government tasked the Royal Society in 2003 to take stock of new challenges in the safety, regulatory or ethical domains that will require societal debate (Royal Society & Royal Academy of Engineering 2004).

Despite such resolutions, and initiatives such as the French national Public Debate (CNDP 2010), coherent involvement of general public stakeholders in the scientific discussion and communication process is still lacking (Savolainen et al. 2013). Moreover, nanotechnologies appear to remain largely unknown by the public (Satterfield et al. 2009). Experts appear overall more optimistic about the potential benefits of nanotechnologies, but also more concerned about their potential long term environmental and health effects (Scheufele et al., 2007; see Siegrist 2010 for a review).

To what extent is the consumer/ taxpayer, who will eventually purchase and benefit from or be harmed by products containing nanomaterials, aware of this technology? Can we today with confidence state, which are the predominant representations? So far, very few studies have systematically explored the "*qualitative* associations and thinking patterns that are most likely to be evoked by the concept of nanotechnology" (Siegrist 2010, p. 843, italics added). Existing studies tend to engage readymade assumptions that nanotechnology is perceived in terms of risks and benefits. For example, Cacciatore, Scheufele, and Corley (2009) identified two types of question which have most frequently framed nanotechnology risk perception research: (a) do the benefits outweigh the risks or vice-versa, and (b) what are the perceived risk and benefits associated with a series of nanotechnology applications? This polarized manner of thinking about nanotechnologies is so intuitive that evidence maps organized in the form of ‘pros’ and ‘cons’ were seen to have improved the reporting of hazard assessments (Wiedemann, Schütz, Spangenberg, and Krug 2011).

What is missing today in the literature is a demonstration of whether the positions of a well-informed population (scientists) mirror the polarized risk-benefit dimension that has dominated research framing to date. To fill this gap, we conducted two studies exploring the representations of nanotechnology by diverse scientists working with these technologies. How is the content of these representations structured? Are these different according to area of scientific specialization? Considering the transit of new ideas from the expert to the lay sphere (Bauer & Gaskell 2008), representations by scientists might hint of what society’s perceptions may look like in the future, once the public is more aware of nanotechnologies, their associated risks and benefits. Our data then, in addition to providing insight on the present specialist situation, might outline the future evolution of representations of nanotechnology in society as a whole.

Public perceptions

In a meta-analysis of 22 studies conducted worldwide between 2004 and 2009 about the public perception of nanotechnologies, Satterfield et al. (2009) found that more than 51% of the participants reported knowing ‘nothing at all’ about nanotechnology. This meta finding is similar to that of 54 % found in a representative European sample (Eurobarometer 2010). This general lack of information on the matter can explain the sensitivity of nanotechnology risk perceptions to framing effects, such as the economic or governance context in which nanotechnology is presented. For instance, greater risk is attributed to this technology when its development is associated with multinational rather than small or medium-sized enterprises (Schütz and Wiedemann 2008). In order to reduce this type of framing effect, some studies have provided participants with information about nanotechnology to support them while forming an attitude (Siegrist, Keller, Kastenholz, Frey, and Wiek 2007). A particular study conducted in Switzerland found the lay public to be significantly more concerned about nanotechnology applications than were experts (Siegrist, Wiek, et al. 2007).

Otherwise, the public seems to endorse an overall positive image of nanotechnologies: seven out of nine studies that specifically asked the question of 'whether judged benefits exceed risks or vice-versa' found that nanotechnology's perceived benefits outweighed its associated risks (Satterfield et al. 2009). This positive assessment of nanotechnology may correspond to a broader and more generic orientation of our modern societies towards 'scientism', or the belief that "science, especially natural science, is much the most valuable part of human learning (…) because it is the most authoritative, or serious, or beneficial" (Sorell, 2013, p. 1).

This positive assessment has been linked to persons' higher familiarity with the issue at hand (Gaskell, Eyck, Jackson, and Veltri, 2005; Retzbach, Marschall, Rahnke, Otto,and Maier, 2011) and with their consultation of scientific media (Ho, Scheufele, and Corley 2010; Scheufele and Lewenstein 2005). In a representative US survey, Ho et al. (2010) found that the more participants claimed to consume scientific media, the more benefits they saw in nanotechnology, and the more they supported its federal funding. These results were similar to those of Retzbach et al. (2011), who found familiarity with nanotechnology to be positively correlated with its perceived benefits and negatively with its perceived risks. These findings encourage a look at the scientific or mass media to learn whether nanotechnologies are being presented there under a positive light.

Media coverage of nanoscience

Studies to date suggest that neither the volume nor the coverage of nanotechnology by the mass media have been sufficient to characterize it as a socially salient, or polemic, issue (Friedman and Egolf 2011; Gaskell et al. 2005). Content analysis of articles about nanotechnology published in newspapers or other online news platforms, demonstrate that the technology is more often covered in terms of benefits than in terms of risk (BfR 2013; Te Kulve 2006). Articles reporting risk information were "overwhelmed by the much larger volume of articles about nanotechnology *benefits* in both United States and United Kingdom" (Friedman and Egolf 2011, p. 1713, italics added). As for the smaller group of articles quoting risk information, unlike the case of controversial biotechnological risk issues (e.g. OGM) alerts about potential nanotechnology risks were frequently issued by *scientists* – and not by environmental or consumer groups (Friedman and Egolf 2011; Pidgeon, Harthorn, and Satterfield 2011). It is interesting to observe that scientists here have appeared more cautious about nanotechnology's possible risks and uncertainties than have other potentially concerned social groups.

Analyzes of how nanotechnology and its applications are being covered by the media, and how they are being received by the public, can provide important indicators of how the potential risks associated to this new technological field are either socially amplified or attenuated (Pidgeon, Kasperson, and Slovic 2003). There are reasons to be attentive: the seemingly uncontroversial and positive view that the public and the media hold about nanotechnology does not mirror the opinion of its experts (Besley, Kramer, and Priest 2008).

Expert perceptions of nanotechnologies

In their process of socialization, experts from different fields are educated within specific scientific traditions and research programs (Patterson and Williams 2005). These scientific traditions, based in research paradigms and worldviews, can significantly influence experts' appreciations of the world. For example, Babbage and Ronan (2000) found academics with a social science background to be more organismically-oriented, and 'hard' (physical/natural) scientists to be more mechanistically-oriented. Therefore, an experts' worldview can be "at least partially determined by the scientific *Zeitgeist* of their field" (Babbage and Ronan 2000, p. 406). The adoption of one paradigm or another can in some cases constitute the difference between conceiving specific realities or not (Kuhn, 1995).

It would therefore be expected that scientists with different backgrounds would have different opinions about nanotechnology (Besley, Kramer, and Priest 2008; Powell 2007). Experts from a physics or chemistry background tend to attribute less health, environmental and social risk to nanotechnology, while experts from a social sciences background acknowledge higher social and regulatory concerns (Besley, Kramer, and Priest 2008). In a similar vein, Powell (2007) found that 'upstream scientists' – engineers, chemists, physicists and materials scientists – tend to think that nanotechnologies do not pose new or substantial risks, while most 'downstream scientists' – toxicologists, epidemiologists and other public health scientists – are 'concerned about the potential environmental and health risks related to these materials' (p. 183).

These studies show that this technology, seemingly uncontroversial in the eyes of the media and the public, is far from being so in the eyes of experts. To study more precisely the representations which are emerging from this new technology, we propose a deeper analysis of how an involved specialist population views nanotechnology. The participating scientists are dealing with this technology on a daily basis: they are part of research groups and networks, refining methods to create, tag, and characterize nanoparticles, furthering measurement and understanding, focussing on industrial and on environmental safety questions, exchanging with their peers research results, definitions, assessments and opinions about nanotechnology. In this sense they not only produce social knowledge in the form of science, but consume it as well, taking active roles in exchanging and confronting nanotechnology's different aspects with their peers.

Social representations

The social representations approach is interested notably in how scientific ideas are integrated by society at large and become shared social knowledge (Moscovici 1961, 2001). During this process of knowledge appropriation, laypeople often resort to metaphors and images that may have little to do with the scientific corpus (Wagner and Hayes 2005). The public proceeds thus to a *reconstruction* of the scientific object on its own terms.

For example, a study in Austria showed that biotechnologies have been represented by the public through images of vegetables as 'infected' or 'monstruous' – which is consistent with the strong rejection for these technologies in the country (Wagner and Kronberger 2001). But when this same technology is framed or anchored in terms of its application to the medical field, it is regarded as positive and desirable (Bauer, 2002; Castro and Gomes 2005). This suggests that when the scientific knowledge about biotechnology reaches the public sphere (through the media, through infomal conversation, etc.) this knowledge has been understood, or anchored, either in terms of medical applications – and thus regarded as being *positive* – or in terms of agricultural applications – and thus regarded as *negative*.

Considering the limited public awareness of nanotechnology (Eurobarometer 2010; Satterfield et al. 2009) and the relatively modest attention devoted to the subject by the media, social representations theory suggests that it would be unlikely for the public to have already formed a unified or systematic representation of nanotechnology. But scientists and experts working directly with these materials are part of another environment – one where nanotechnologies are the subject of daily encounters, casual talks, and thus of social representations.

Overview of the studies

Our goal in this paper is to analyze the representations that experts in nanotechnology from different fields share about the science in which they are actively engaged. To more systematically analyze this group's social representations of nanotechnology, we have conducted two studies. A first exploratory study aimed to identify the main dimensions behind these experts' nanotechnology representations. The second study set out to test the validity of these dimensions with a wider international sample of nanotechnology experts.

Study 1 – Exploring scientists' representations of nanotechnology

Social representations can be considered to be a set of shared beliefs. But more than shared beliefs, social representations also contain logically organized differences, or *organizing principles*. Organizing principles 'do not necessarily consist of shared beliefs, as they may result in different or even opposed positions taken by individuals in relation to common reference points' (Doise, Clémence and Lorenzi-Cioldi 1993, p. 4).

Considering the importance of understanding the social logic behind the nanotechnology representations, our first study sought to explore (1) the content that scientists more often associate with nanotechnology – what is *commonly* shared; (2) the dimensions organizing any distinctions within this content – what are the *differences* across subjects.

Method

Participants

Thirty-nine researchers involved in a multi-disciplinary European project centred on methods development for assessing the environmental fate and effects of engineered nanoparticles[5] answered an online questionnaire between April and May 2011. This group was composed of scientists from fields such as biology, toxicology, physics, and environmental sciences, but individual replies were not identified by disciplinary background. The scientists were personally contacted by email and the results of analysis were presented to them and discussed in a project plenary meeting.

Procedure

Participants were asked 'When you think of NANOTECHNOLOGY, what are the five words or notions that first come to your mind?'. These free associations were then categorized – synonyms, plural forms and short phrases were reduced to a corresponding more frequent simple form.

Secondly, these categories were submitted to a multiple correspondence analysis (MCA) (Doise, Clémence and Lorenzi-Cioldi, 1993; Carvalho, 2008), which is a type of factor analysis suited for the analysis of categorical data. This analysis was performed with the goal of identifying, through a quali-quantitative procedure, the main oppositions (Billig et al. 1988) used by scientists to convey meaning to nanotechnology. This analysis is also recommended when the goal is to find relations within categories of variables under analysis (Carvalho, 2008), which in our case are the different content categories spontaneously associated with nanotechnology. The multiple correspondence analysis was run in IBM SPSS (Statistical Package for Social Sciences) version 19.

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[5] NanoFATE (2010-2014), large-scale collaborative project n° CP-FP 247739 under EC FP7-NMPENV-2009 (Theme 4), coordinated by C. Svendsen, NERC.

Results

Participants associated 104 different words to nanotechnology, which after the categorization were reduced to 20 different forms. The categories most frequently associated with nanotechnology were: ‘new products’ (n = 27), ‘small’ (26), ‘risk’ (23), ‘new’ (11), ‘nanoparticles’ (10) ‘opportunity’ (9), ‘uncertainties’ (9), ‘environment’ (8), ‘new properties’ (7), ‘revolution’ (6), ‘medicine’ (6) ‘legislation’ (6) and ‘industry’ (6). These free associations show in brief that nanotechnology experts consensually think about nanotechnology in terms of nanoscale (*small*), rendering *new products* possible, which involves some unknown *risks*.

In order to explore the differences within this content, these free associations were arranged in a 20 (association category) X 39 (participants) contingency table that was then submitted to the multiple correspondence analysis. Of the resulting explanatory factors, the first two dimensions together explained 26.5 % of the total variance[6] of the original matrix.

The first dimension explains 14.1% of the total variance (Table 1). This dimension expresses the tension between the opportunity for new products enabled by the small size of the nanoparticles *vs*. concerns related to the possible risk that these technologies might represent for the environment and for the human health. Thus, enthusiastic thinking typified by the categories labelled medicine and opportunity, appears to be counterposed by preoccupations typified by the categories of risk, health and environment and legislation. This dimension was therefore named ‘opportunity-risk’ (Table 1).

[6] This analysis took into account only those categories contributing to the dimension more than the dimension’s inertia, as indicated in Table 1.

Table 1. Dimensions explaining the response categories of nanotechnologies.

Dimension	Cronbach's α	Inertia	% of Variance
1. Benefit-risk	.68	.14	14.1%
2. Opportunity-toxicity	.63	.12	12.5%

The second dimension explained about 12.5% of the total variance (Table 1). It expresses the tension between new opportunities opened by the technology (associated categories: opportunity, medicine, innovation) *vs.* new risky properties and risk potential (associated categories: new properties, toxity and reactivity) (Figure 1). This dimension demonstrates a polarity similar to that of the first dimension – with the difference being that the 'risk' end of this second dimension focusses on the essential properties and mechanistic effects of nanomaterials, rather than on large-scale impacts.

When free association categories are projected on the plot defined by these two axes, three groups of response can be identified (Figure 1). On the first dimension we can see the differentiation between 'opportunities' on the lower righthand side and the risks that are generally associated with nanotechnology (in terms of large-scale impacts, i.e. for human health and the environment), on the lefthand side. The second dimension distinguishes between nanotechnology's opportunities, presented in the lower part of the chart (medicine, innovation and industry) and the possible risks inherent to nanomaterial characteristics and effects, presented in the upper part of the chart (Figure 1).

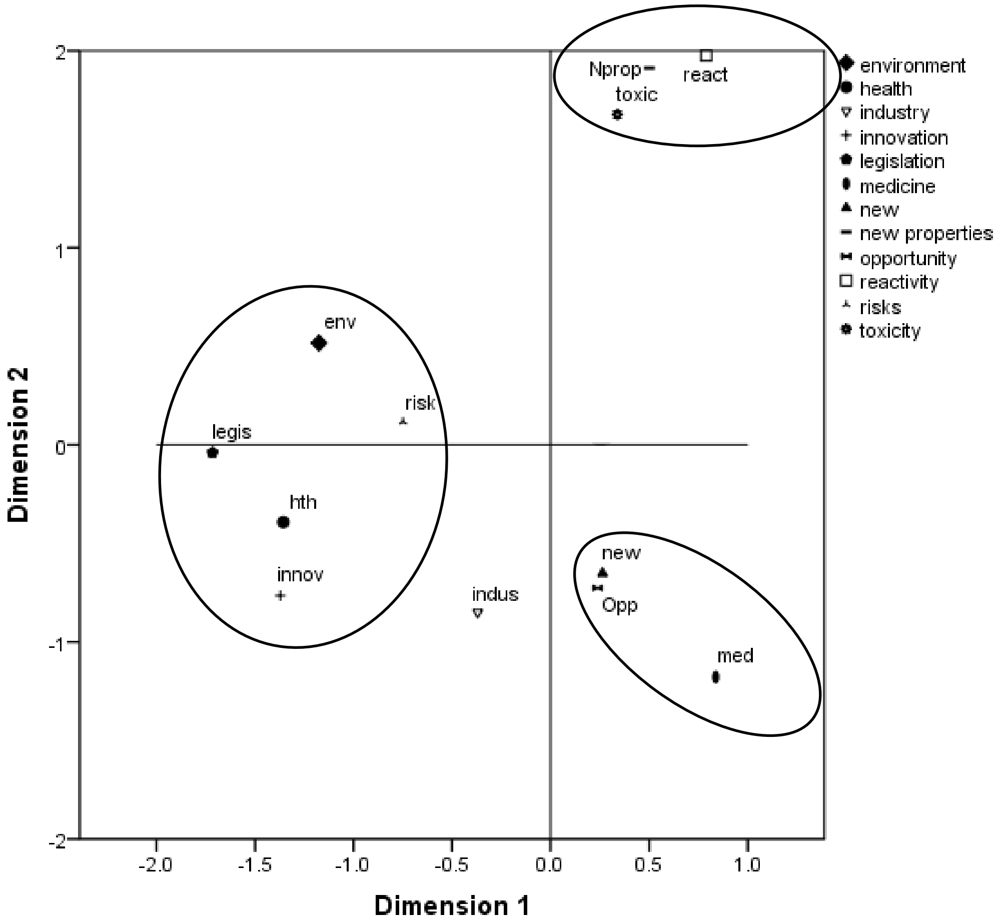

Figure 1. Groupings of categorized free-associations to 'nanotechnology'.

Discussion

Public perceptions of nanotechnology have been mainly assessed in the past through polarized instruments, as if the technology was – and should be – understood essentially in terms of 'pros' and 'cons' (Besley, Kramer, and Priest 2008; Cacciatore, Scheufele, and Corley 2009; Pidgeon et al. 2009). Past studies surveyed participants about the degree to which they perceived either risk or opportunity in the development of nanotechnology, *assuming* that this technology would be represented in a bipolar manner opposing negative aspects (risk) and positive aspects (benefit, opportunity). To our knowledge, however, this representation of nanotechnology as a polarized issue had not yet been confirmed by a qualitative analysis.

We performed the qualitative analysis, without imposing the risk/benefit categories. Our results show that the experts from different scientific backgrounds participating in the NanoFATE project generally think of nanotechnology in terms of scale (*small*), enabling *new products*, which involves some unknown *risks*.

But these generally shared ideas can be divided into different sub-groups of response, distributed along two main dimensions. If on the one hand the scientists accentuate the possible benefits and opportunities enabled by this new technology, on the other hand they call attention to potential risks for the environment and society as a whole (Dimension 1), because of new or essential properties associated with the nanoscale (Dimension 2). Interestingly, these statistically meaningful dimensions of representation are indeed echoed in the very research objective of NanoFATE, which set out to determine whether the environmental safety or risk of nanomaterials ('risk' end of Dimension 1) can be assessed with classical methods, or whether the intrinsic characteristics of selected nanoparticles and their mechanisms of action on the environment ('risk' end of Dimension 2) differ so much from ionic (non-nano) forms of the same materials that specific methods would be needed (see e.g. NanoFATE 2012).

Public thinking and meaning-making often take the shape of a debate, or a dilemma, where 'socially shared images, representations and values can be seen to conflict' (Billig et al. 1988, p.14). Our results suggest that this particular group of nanoscientists also think and argue about nanotechnology in a polarized manner, limiting their enthusiasm about the technology – a representation that is more widespread in the media (Friedman and Egolf 2011) – with concerns about possible environmental and health risks, potentially rooted in the particular characteristics of materials at the nanoscale. In this way, our Study 1 provides a confirmation of the bipolar risk-benefit representation of nanotechnology, derived for the first time from a quali-qualitative analysis.

What we do not know from these results is whether this simultaneous understanding of nanotechnology as opportunity and as risk is shared by *all* scientists, irrespective of their background, or if the particular representation emerging here may mirror different perspectives by subgroups of experts over this social object (Babbage and Ronan 2000; Doise 2001).

If the factor dimensions revealed here are both broadly shared by individual experts, we could understand this polarization as part of an argumentative pattern constructed as *yes… but* (Mouro and Castro 2010). *Yes*, nanotechnology is a novelty associated with great future opportunities that will improve our lives; *but* it comes with some unknown qualities and potential risks for the environment and human health.

However, the two dimensions found in this study might alternatively indicate the existence of two different representations distinguishing subgroups with a common background but different sensibilities, leading them to 'cluster' at either end of the overall risk-opportunity field. This could point to the existence of different perspectives (or anchors) for the representation of nanotechnology as a function of the group of experts (Babbage and Ronan 2000; Doise 2001; Doise, Clémence and Lorenzi-Cioldi 1993). Different scientific paradigms possibly co-exist in relation to nanotechnology (e.g., Kuhn, 1995; Patterson and Williams 2005) influencing some to orient their representations towards opportunities, while others might delineate their representations principally according to the risks that may be seen at the material level or broader impact levels. Previous studies have already indicated the existence of differences in the way that experts from different specialities perceive nanotechnology (Besley, Kramer, and Priest 2008; Powell 2007). The NanoFATE project, whose members furnished the data of Study 1, was indeed remarkable in that it engaged a very diverse set of scientific backgrounds and skills needed to produce an integrative assessment of environmental fate and risks of engineered nanoparticles (NanoFATE 2010; 2012). However, participants' particular discipline was not surveyed in Study 1. In the next study we propose to explore, through replies from a wider group of nanoscientists, whether the polarized representation of nanotechnology (as opportunity-risk) is shared by all of them, or if one of these poles can be attributed to some groups of experts more than to others.

Study 2 – Exploring the opportunity-risk dimension of the nanotechnology representation

The second study had two objectives. The first was to test the polarized risk-opportunity nature of nanotechnology's social representations, as demonstrated by the first (dominant) dimension of the previous study. Our second objective was to identify whether experts with different backgrouds are more (or less) inclined to represent nanotechnology as risk or as opportunity.

These two objectives were addressed by developing a new survey instrument based on the results of the first study, further grounded through a focus group and a review of Internet contents (details in the method section). This nanotechnology appraisal instrument consisted of a list of items reflecting different positions toward nanotechnology, in relation to which participants were requested to express their level of agreement. An enlarged sample of nanotechnology specialists was surveyed.

In this part of the paper, we will present an exploratory study of the structure of this instrument. The different perceptions of nanotechnology will then be compared in relation to the different roles and scientific backgrounds of participating nanotechnology experts.

Method

Participants

Our sampling frame was composed by a mailing list of a major European nanotechnology research group, the EU NanoSafety Cluster. The *EU NanoSafety Cluster* is an initiative that intends to maximize the synergies between the existing European research projects addressing all aspects of nanosafety including toxicology, ecotoxicology, exposure assessment, mechanisms of interaction, risk assessment and standardization (http://www.nanosafetycluster.eu/). The sampling frame also included persons attending a workshop on the EU 2nd Regulatory Review of Nanomaterials (cf. Schneider 2013). Our initial sample consisted therefore of 771 email addresses of scientists interested in nanotechnology, regulators and administrators.

An invitation to participate in a '5-minute survey of societal perceptions of nanotechnology' was sent the total 771 email addresses between December 2012 and February 2013. Thirteen email invitations bounced, leaving us with a sample of 758 persons with professional involvement in nanotechnology who received the email containing a link to the online survey tool. One hundred and sixty-three persons responded to the online questionnaire, corresponding to a response rate of approximately 21%. Considering that we do not have data about characteristics of all participants constituting our sample, we could not control for possible sampling errors or self-selection biases.

The group of participants that *did* respond to the questionnaire includes experts with different roles in the development of nanotechnology and also with different scientific backgrounds. Our sample was mostly composed of researchers (66.4%), followed by policy actors (17.1%), administrators (15.1%) and regulators (5.9%) (participants could describe themselves with more than one response).

The *main* scientific background represented was environmental sciences (38.2%), followed by engineering (27.3%), toxicology (19.7%), biology (19.1%), physics (16.4%), chemistry (15.1%), social sciences (9.2%), medicine (7.2%) and pharmacy (2.6%). Some participants described themselves as having more than one type of scientific background. This distribution encompasses participants with very different standpoints from which they 'frame' the characteristics and the uncertainties of this new technology (Powell 2007; Althaus 2005).

Instrument

The nanotechnology appraisal instrument was informed by the categories identified by the first study. The individual items were grounded in more elaborated concepts emerging from one focus group conducted by the lead author with five nanotechnology researchers of different backgrounds (biologists, toxicologists and engineers) and from different departments at Universidade de Aveiro, in Portugal. The group identified its own themes and discussed various aspects related to nanomaterials, including in particular: their potential 'toxicity'and 'reactivity', the need to raise 'public awareness' and the need to 'regulate' these technologies. After the group session, the lead author summarized the main ideas brought up by the group and submitted the summary to the five researchers for validation. The instrument was then completed by including characteristic phrases used by these specialists to refer to nanotechnology, alongside statements drawn from journals, institutional websites or research projects' dissemination websites.

Survey participants were required to judge their level of agreement with a series of 13 statements using a scale from 1 (totally disagree) to 5 (totally agree). Within this list were items considered by the authors to tap primarily the 'opportunity' or the 'risk' poles identified in the first study, forming two subscales. Some statements were formulated in the affirmative (e.g. *‘nanotechnology is an important sector for European economic development and competitiveness’*) while others were 'reversed' (e.g. *‘the development of nanotechnology will NOT create many jobs’*). The overall order of item presentation was randomized to control response biases. Responses to the items formulated in the negative were reversed before analysis.

Results

Responses to the 13 items composing the nanotechnology appraisal instrument were submitted to a Principal Component Analysis (PCA) to explore the relation between the two proposed subscales. Varimax rotation revealed the existence of two factors clearly corresponding to the representations of nanotechnology as risk or as benefit or opportunity (KMO = .85; Bartlett’s test of sphericity: $\chi(78) = 596.13$, $p < .001$). These two factors accounted together for 49.5% of the total variance (Table 2).

Table 2. Nanotechnology appraisal items and their loadings on each of the factors.

	Opport. (34.05%)	Risks (15.45%)
13. Nanotechnology is an important sector for European economic development and competitiveness.	*.77*	.05
14. It is in the interest of society to support the development of nanotechnologies.	*.74*	-.31
17. Today’s innovations in nanotechnology will foster a large number of scientific advances in the future.	*.71*	-.22
15. Some of our environmental problems can be addressed by good application of nanotechnological advances.	*.70*	-.29
11. In future years, people will think of nanotechnology as a real industrial revolution.	*.66*	.21
16. Human health applications of nanotechnology have great potential.	*.62*	-.14
12. The development of nanotechnology will NOT create many	*.56*	-.16

jobs (reversed).		
7. The development of nanomaterials should be under strict regulatory control.	-.12	*.76*
5. No evidence to date suggests that nanomaterials present novel risks (reversed).	.10	*.68*
8. The precautionary principle should guide decisions made about nanotechnologies.	-.11	*.67*
1. There is reason for concern about the impact that an increasing use of nanomaterials may have on environmental health.	-.19	*.65*
9. The principle "no toxicological data, no market" should apply to nanomaterials.	-.23	*.63*
3. The potential risks associated with nanotechnology developments outweigh their future benefits.	-.22	*.51*

Considering the good internal consistency of both the risk (Cronbach's α = .82) and the opportunity (α = .76) scales, each of them was averaged in a single measure of risk and opportunity. These two measures correlate negatively ($r = -.37$, $p < .01$), which means that the more one person adheres to one of these aspects of the representation, the less s/he adheres to the other.

The empirically demonstrated division of items into two main dimensions of risk and opportunity confirm that experts represent nanotechnology in a polarized way, exactly as we had found in the previous study. Moreover, the negative correlation between the aspects of risk and opportunity indicate that participants adhering to one of these representations tend to not adhere – or adhere to a lesser extent – to the other representation. Let us now explore how specialists with different roles and/or scientific backgrounds emphasize specific elements of the nanotechnology representation – the particular manner in which they may tend to cluster in the polarized field traversed by the risk/opportunity dimension.

Representing different perspectives

To better understand how the expert's *role* influences perceptions of nanotechnology as risk or as opportunity, two one-way anovas were performed on their attribution of risks and of benefits to nanotechnology. No significant differences were observed between the way in which experts in different roles regard nanotechnologies as opportunities ($F(3,122) = 1.26$, $p = ns$) and as risks ($F(3,122) = .95$, $p = ns$). Even if not significantly different, trends of response could however be distinguished (Figure 2). Participants occupying administrative positions tend to see more opportunities in nanosciences (M = 4.14), while those in the role of regulators tend to see fewer (M = 3.73). Concerning the perception of risk, policy actors tend to attribute more risk to nanotechnology (M = 3.68), while researchers tend to attribute less (M = 3.4) (Figure 2).

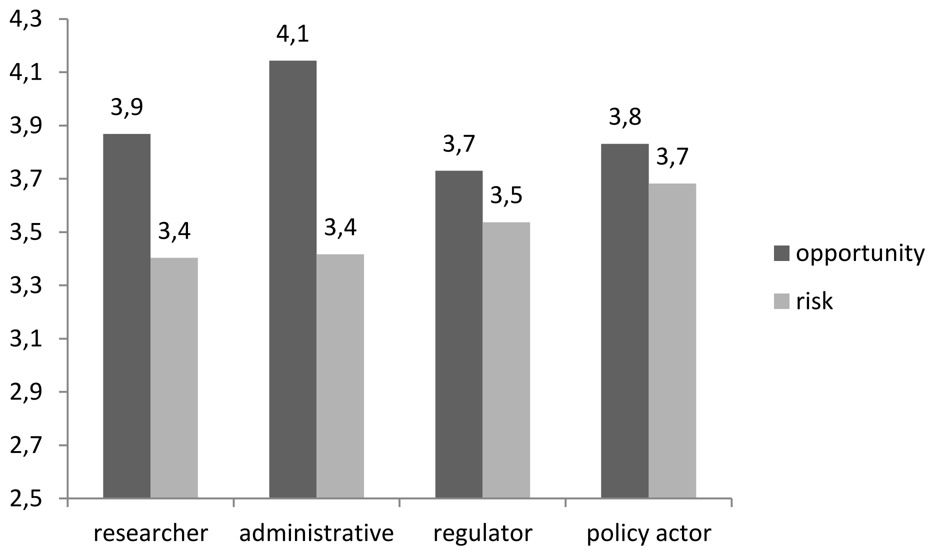

Figure 2. Means of opportunity and risk attributed to nanotechnology per role.

In order to better understand how the respondent's *scientific background* (and not their role) influences perceptions of nanotechnology as either risk or benefit/opportunity, two one-way anovas were performed.

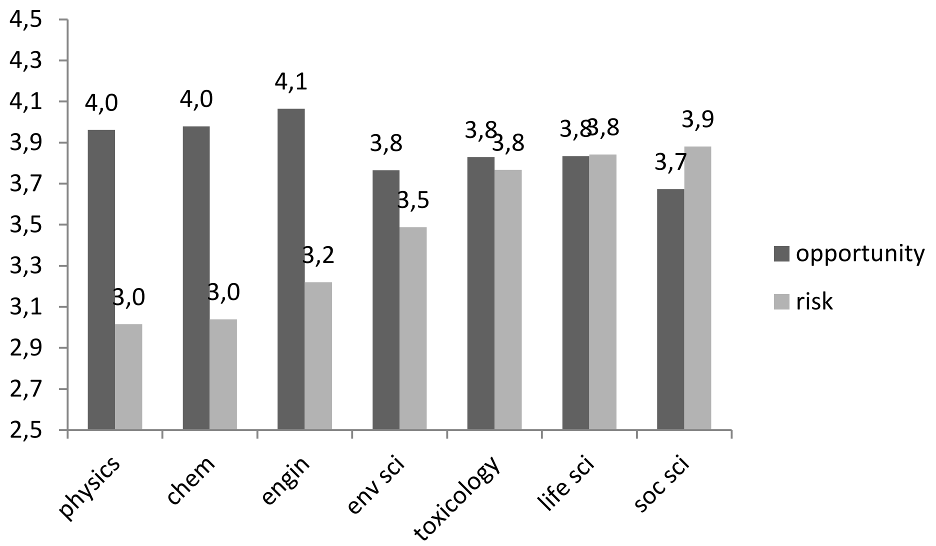

Figure 3. Means of opportunity and risk attributed to nanotechnology per scientific background.

Participants with different scientific backgrounds did not significantly differ in their representation of nanotechnology as opportunity ($F(6,136) = .98$, $p = ns$). This means that the surveyed experts, irrespective of their scientific background, acknowledged the opportunities or benefits presented by nanoscience (Figure 3).

The perception of risks, on the other hand, was not as consensual: experts with different scientific backgrounds agreed to a different extent with items attributing risk to nanotechnologies ($F(6,136) = 5.47$, $p < .001$). Post-hoc tests with Bonferroni pairwise comparaisons showed that scientists whose scientific background includes physics or chemistry attribute significantly *less risk* to nanotechnologies when compared with the group whose scientific background is in toxicology, life sciences (biology and medicine), and social sciences (all p's $< .05$). Finally, the group of experts indicating a background in engineering or environmental sciences was not distinguished from any of the other groups regarding their risk perception (Figure 3).

Overall, these results indicate that, despite a consensual view among experts that nanotechnologies represent a great opportunity, depending on scientific background they do not agree to the same extent that nanotechnology also constitutes a risk. We can identify therefore two main arguments, styles of discourse or subgroups: one that more consensually represents nanotechnology as opportunity, and another one that represents it as *both* an opportunity and as a risk.

Discussion

Our Study 2 validated the polarized representation of nanotechnology found in the first study: nanotechnologies are seen as great opportunities, but they also involve unknown risks. Our results also permitted the analysis of how the experts' standpoint (role and discipline) might influence their representations (Powell 2007).

Nanotechnology representations were not significantly influenced by the role played by the participating specialists. We note that the roles can be performed in very different ways depending on the participants' scientific background. This could blur the differences between the perspectives adopted by participants in different roles.

On the other hand, the experts' scientific backgrounds clearly influenced, on the other hand, the way they represented nanotechnology. Despite a consensual view across experts that the development of nanotechnology provides important opportunities, they do not agree about the extent to which it constitutes a risk. 'Hard science' experts see *less risk* in nanotechnology than do life and social scientists. Environmental scientists and engineers were not fully assimilated to nor distinguished from either of these subgroups. This finding suggests that they are a more diversified group, containing persons who attribute respectively more and less risk to nanotechnologies (Figure 3).

Our results indicate that the twofold representation found in Study 1 is actually shared by only part of the broader Study 2 sample – the subgroup of life and social scientists – who in a 'yes, but' logic regard nanotechnology as simultaneously *both* opportunity and risk. As our results indicate, this dualistic view of nanotechnology as containing both opportunities and risks constitutes a paradigm adopted by only part of the researchers in our sample. By using one paradigm or another, scientists are prepared to observe different realities (Kuhn, 1995) where different possibilities of applications are also associated with different concerns (Siegrist et al. 2007). It is therefore possible that our results mirror judgements of risks and benefits made towards different 'nanotechnologies'.

The group composed of 'hard scientists' shares a view of nanotechnology that is mainly built on associated opportunities. These results are in line with previous results about (1) the relative lack of concern of hard science experts with nanotechnology's possible risks and (2) the concerns of environment and human health experts regarding these new technologies (Besley, Kramer, and Priest 2008; Powell 2007).

General discussion

Considering that the public is still insufficiently aware of nanotechnologies (Eurobarometer 2010) to have forged by itself a stable or uniform representation of this issue, we propose in this paper a systematic assessment of how nanotechnology experts represent this object. The question here is not to investigate differences between the perceptions by the expert and by the layperson. Rather, it is to explore the way in which experts informally understand nanotechnologies. Future research could investigate if and how these experts' ideas will make their way into the social representations of larger population groups.

In a first study we have shown that nanotechnologies are generally thought of by nanoresearchers in terms of nanoscale (*small*), enabling *new products*, which involve some unknown *risks*. These shared beliefs can be differentiated along two dimensions that distinguish (1) opportunity vs. risk impacts for the environment, health and society associated with this new technology and (2) opportunity vs. risks specifically associated with the characteristics of nanomaterials (i.e. toxicity and increased reactivity). To our knowledge this is the first empirical demonstration, via qualitative analysis, of a polarized representation that up to now researchers have simply *assumed* to exist.

The polarized representation of nanotechnology as simultaneously both opportunity and risk was then confirmed in a second study with a larger sample of nanotechnology experts. The nanotechnology appraisal replies were factor-analyzed and yielded two main factors: one indicating a representation of nanotechnology as opportunity and another indicating nanotechnology as risk.

Then, these representations were analyzed first according to our participants' roles, and secondly according to their scientific backgrounds. Representations of nanotechnology as risk or opportunity were not different across the professional roles fulfilled by respondents. In contrast, scientific backgrounds do reveal differences in the way experts make sense of these new technologies. 'Upstream', physical or 'hard' scientists tend to represent nanotechnologies in terms of opportunities and not in terms of risks. Environmental, life, and social scientists tend to share a more complex or twofold representation in line with that found in the first study: nanotechnologies represent great opportunities which still are accompanied by unknown risks, described at different scales (material or environmental and societal). These results confirm a similar distinction found elsewhere between 'hard' and 'soft' or life scientists where the latter tend to be much more concerned about nanotechnologies than the former (Besley, Kramer, and Priest 2008; Powell 2007). A fruitful direction for further research would be to extend our Study 2 and its nanotechnology appraisal scale to a sample of industrial actors with their various roles and backgrounds.

Our findings indicate that measuring experts' – and later on citizens' – perceptions of risks and benefits related with nanotechnologies opens perspectives beyond a 'risk acceptance' paradigm (Slovic 2000). We have demonstrated that the benefits or opportunities provided by nanotechnologies may be broadly acknowledged, but at the same time scientists trained in specific research programs (Patterson and Williams 2005), referring to different paradigms (Kuhn, 1995) and worldviews (Babbage and Ronan 2000), can be more or less equipped to acknowledge the risks associated with this emerging field of technology – their scale, their impact, and indeed perhaps their significance or meaning for society. In this way, agreement on *opportunity or benefit* will not be a predictor of *acceptance* (if indeed acceptance is correlated with perceptions of risk).

Scientific backgrounds constitute the lens through which experts themselves cognitively construct these issues. This twofold perception of nanotechnology as both opportunity and risk may be meaningful also in other other risk fields: people only engage in conversation (which generates social representations) because of the ambivalence that arises from the duality between an issue's positive (good products and medical advancements) and negative (risk) aspects. If only positive or only negative aspects were present, societal debate on a given issue would be far less pronounced in comparison with e.g. what is observed today in relation to the climate change debate, where skepticism has quickly gained momentum over the last years (Jaspal, Nerlich, and Koteyko 2012; Smith and Leiserowitz 2012).

Our results show finally that a seemingly consensual view by scientists regarding nanotechnology as conveyed by the media (Friedman and Egolf 2011) – and subsequently adopted by the public (Ho, Scheufele, and Corley 2010; Scheufele and Lewenstein 2005) – is in fact open to discussion. The restricted media attention to nanotechnology as potential risk does appear to rely on alerts voiced by scientists (Friedman and Egolf 2011; Pidgeon, Harthorn, and Satterfield 2011). One hypothesis could be that the media present mostly the uncontroversial view of only part of the nano community, focussed on the consensual view of the opportunities it offers – then providing less space for arguments and reflections from the other scientists who see reasons to be concerned, and who according to our findings distinguish quite finely different scales of risk and impacts. Overall, it is the subtlety of these scientists' thinking which may be artificially reduced by the media to a somewhat one-sided discussion. Yet, as representations of nanotechnology disseminate in society, good governance will require the capacity to entertain all sides of the question as well as the meanings of eventual trade-offs between opportunity and risk.

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