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Risk and society

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Risk, benefit, and regulation: Attitudes towards nanomaterials and nanotechnology among Swedish expert stakeholders

Abstract:
The aim of this study is to investigate attitudes towards nanomaterials and nanotechnology among Swedish expert stakeholders. The study explores the views of these experts on a number of topics in connection to nanotechnology innovation with a focus on perceived risk, perceived benefits, risk regulation, and risk management. In January 2017, we distributed a web-based questionnaire to 237 individual experts at government agencies, business corporations, and other relevant organisations. The experts had a self-rated interest in, or connection to, nanomaterials and nanotechnology in their work at their organisation. This study contributes to a multidisciplinary research field addressing questions about innovation and foresight, risk perception, and regulation of nanomaterials and nanotechnology in the public domain.

This study makes several claims.

1. The topic of nanomaterials and nanotechnology engages a broad range of Swedish stakeholders in many different ways, including, but not limited to, research and research funding, risk assessment, product development, as well as regulation and legislation.
2. Experts generally emphasize the benefits of nanotechnology and nanomaterials, but perceived benefit and perceived risk varies with educational background and organizational affiliation.
3. How experts assess risk and benefit varies depending on area of application (for example medicine, cosmetics, coatings, electronics, agriculture and food).
4. Experts are generally supportive of further regulation of nanomaterials and nanotechnology. They are relatively negative to taxation and self-regulation as regulatory measures and relatively positive to selective prohibition. There is also disagreement over appropriate regulatory measures among respondents.
5. High perceived risk correlates with a more positive attitude to regulation, and high perceived benefit correlates with lower support for regulation.
6. A common and shared belief is that regulation should be based on science, and that public involvement is undesirable.

Keywords: nanomaterials, benefit, risk, innovation, regulation

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1. Introduction

Nanotechnology innovation is rapidly growing on a global scale. Nanotechnology is often defined as the study and/or manipulation of matter where at least one of the dimensions of the manipulated matter is below 100 nm. The uniqueness of nanoparticles is that their properties can be selectively controlled by controlling the size, morphology, and composition of constituents. By using techniques for manipulating matter on this scale, matter can obtain new qualities with a wide range of applications. Areas of application and use include electronics, food and food packaging, textiles, health care, drugs, medical diagnostics, coatings, and cosmetics. At the present time, nanomaterials and nanotechnology are used in many different areas, and it is predicted that future nanomaterial and nanotechnology innovations will contribute to more resource effective production, improved healthcare, new jobs, and economic growth.

However, although nanotechnology is often associated with the promise of future innovation, nanoparticles and nanomaterials also pose challenges for risk management and regulation. Toxicity of chemicals at nanoscale is not predictable from the toxicity of the same material in bulk or molecular form. Hence, there are substantial uncertainties about toxicity, future exposure and use, and long-time consequences of nanoparticles to nature and ecosystems. Risk assessment and risk management of nanomaterials therefore poses many challenges (Miller & Wickson, 2015; Renn & Roco, 2006). Nanomaterials and nanotechnology include a wide range of materials and techniques that are covered by a patchwork of laws and regulations. Consequently, there is no overarching framework for risk assessment in place. Thus, methods for description, characterization, and testing of nanomaterials are still partly lacking (OECD, 2012, 2013).

Assessment of toxicity of nanomaterials is highly demanding due to the systemic and structural complexities involved in the physical-chemical-biological interactions taking place at nano-level for any specific nanomaterial. New risks with nanomaterials and nanotechnology can be characterized by uncertainty and systemic complexity. The risks transcend established regulatory and institutional boundaries, and fit poorly into traditional regulatory frameworks. Nanomaterials constitute a case in point that may call for new ways of developing regulations (Grieger, Baun, & Owen, 2010), and for authorities better apt to handle complex and international product-chains (Beaudrie, Kandlikar, & Satterfield, 2013; Wang, Gerlach, Savage, & Cobb, 2013). Due to the high level of uncertainty, and the highly resource demanding methods for risk assessment, it has been argued that stakeholder deliberation is a key element for the successful development and the safe use of nanomaterials and nanotechnology (Hansen, 2010; Renn & Roco, 2006). The establishment of trustworthy, legitimate, and efficient governance frame-works for the regulation of nanomaterials will demand inter-institutional and inter-organizational collaboration from a broad range of societal actors.

The development and regulation of nanomaterials and nanotechnology involves a variety of institutions and organizations in society. While many organizations work with the promotion of nanotechnology, others strive to ensure that the technology and the materials used are safe for humans and the environment. Expert stakeholders in government, industry, or interest organisations have a privileged position since they often translate between science and policy. They can influence regulation, decision-making, and implementation of regulation, and by participating in the public debate they contribute to shaping public understanding. Expert stakeholders, therefore, can be expected to play an important role in the development of the safe management of nanotechnology.

Among diverse organizations engaging in the development and regulation of nanomaterials and nanotechnology there is a shared concern to promote the safe development of useful nanotechnology innovations and applications. However, as is well established in previous research, societal actors have different roles in society and different perspectives and concerns relating to their roles and responsibilities (Apostolakis & Pickett, 1998; Jenkins-Smith & Bassett, 1994). Societal actors such as government authorities, industry, civil society, as well as other organizations in society follow diverse and divergent institutional logic. Such institutional logic will constitute different principles for formulating problems, finding solutions and establishing relevance of information, resulting in different rationalities for decision making (Luhmann, 1989). Different categories of stakeholders can be expected to have divergent attitudes and values, different understandings of benefits and risks, and different attitudes to regulation of nanomaterials and nanotechnology. Knowledge of such perspectives, and on what terms they agree or disagree on problem definitions and solutions is essential for successful and efficient societal management of potentially hazardous nanomaterials.

From this perspective, the current study investigates the views of Swedish expert stakeholders on a number of issues and challenges regarding nanotechnology innovation. The expert stakeholders all work in organizations in Swedish society; in government, industry and civil society. These experts do not necessarily need to have a self-rated extended knowledge or experience of nanomaterials/ nanotechnology, but they do come into contact with such issues in their professional role.

The overall aim of this study is to provide an overview of perceptions and attitudes of Swedish expert stakeholders. Our ambition has been to broadly include all expert stakeholders in Swedish society currently involved in some way with nanotechnology. We have investigated how they perceive risks and benefits with nanomaterials and nanotechnology in general, and also in relation to more specific areas of application. Furthermore, we have investigated stakeholders' preferences for, and ideas about, what regulatory tools are appropriate for nanomaterials and nanotechnology. The study explores similarities and differences between categories of actors in relation to their roles in society, and also how other factors such as gender, educational background and self-rated knowledge influence the experts' understanding.

This study answers to the following research questions:

RQ1: In what ways do expert stakeholders in Swedish society engage with issues concerning nanomaterials and/or nanotechnology?

RQ2: How do expert stakeholders understand risk and benefit in relation to nanomaterials and nanotechnology?

RQ3: How is risk understood to be manageable by expert stakeholders in relation to nanomaterials and nanotechnology? And, what regulatory tools are preferred?

Drawing on previous research on experts' perception of nanotechnology we have formulated a number of hypotheses in order to structure and guide the inquiry of this report to help answer the research questions.

Hypothesis A
Perception of benefit with nanomaterials and nanotechnology will be higher compared to risk.

Hypothesis B
There is a difference in risk perception depending on the overarching value at stake: the environment, human life and health, and society at large.

Hypothesis C
Risk for human life and health is rated higher than environmental risk.

Hypothesis D
Risk and benefit perceptions influence each other negatively so that higher benefit perception with nanomaterials and nanotechnology are associated with lower risk perception.

Hypothesis E
Rating of benefit with nanomaterials and nanotechnology vary depending on area of application.

Hypothesis F
Rating of risk with nanomaterials and nanotechnology vary depending on area of application.

Hypothesis G
Benefit is rated higher compared to risk for all areas of nanotechnology application.

Hypothesis H
Nanotechnology applications within the application area agriculture and food have higher perceived risk and less perceived benefit compared to applications within medicine and medical care.

Hypothesis I
Perception of risk and benefit depend on field of expertise and educational background.

Hypothesis J
Experts with expertise in physics, material science, and engineering (upstream scientists) have higher perception of benefit and lower perception of risk. The pattern is reversed for experts with expertise in toxicology (downstream scientists).

Hypothesis K
High perception of risk is connected to support for further regulation.

Hypothesis L
High perception of benefit is not connected to support for further regulation.

Hypothesis M
Attitude to regulation varies with respondent's organizational affiliation.

Hypothesis N
NGO and government experts are more concerned about risk compared to trade organization and industry experts.

Hypothesis O
NGO and government experts are more supportive of regulation of nanomaterials and nanotechnology compared to trade organization and industry experts.

This report proceeds as follows. *Chapter 2* presents previous research on stakeholders and experts understanding of nanotechnology, and will thus provide a more in-depth understanding of the inquiry in this report. *Chapter 3* describes how the study was accomplished, and the method used: the selection of respondents, the development of the questionnaire, and how the interpretation and analysis of empirical data has been carried out. *Chapter 4* presents the results and analysis of the data. This chapter is divided into three sub-sections: 1) the population of expert stakeholders with regard to organizational affiliation, educational background, and level of self-rated knowledge; 2) perceived benefits and risks of nanomaterials and nanotechnology; 3) preferences for and ideas about regulation. *Chapter 5* discusses the results and analysis as it relates to previous research. *Chapter 6* offers a brief summary and a conclusion of the report.

2. Previous research

There is a growing body of research literature about public and expert attitudes to nanotechnology. Some studies focus on scientists working at universities with the development of nanomaterials or with risk assessment (Johansson & Boholm, 2017), while others focus on expert stakeholders working at government agencies, industry and NGOs. Experts' views on nanotechnology have been considered worthy of study for several reasons. It has been argued that expert views are likely to influence media as well as public opinion (Gupta, Fischer, George, & Frewer, 2013; van Dijk, Fischer, Marvin, & van Trijp, 2015). Van Dijk et al. argues that "expert stakeholders in academia, industry, public interest groups and government play a role in shaping public opinions towards innovations, through their participation in the public debate and information distributed in the media […], and by contributing to the creation of industry or political decisions" (van Dijk et al., 2015, p. 278). Studies of scientists' and expert stakeholders' understanding of nanotechnology innovation is situated in a research tradition that looks into how understanding of risk is shaped by heuristic or conceptual frameworks (Slovic, 2016) and varies with factors such as gender, perceived benefit, and organizational affiliation. From this perspective toxicity, proximity to material, and exposure are but few of many other determinants influencing experts' risk assessments (Gupta, Fischer, van der Lans, & Frewer, 2012).

Experts' perception of risk has been shown to vary through a number of different factors, and van Dijk et al. argue that both risk perception and benefit perception form a "complex multidimensional construct in the mind of experts" (van Dijk et al., 2015, p. 293). A study from 2007 from the U.S. suggests that experts perceive lower risk compared to the general public (Siegrist, Keller, Kastenholz, Frey, & Wiek, 2007). Another study of U.S. nanotechnology researchers (Besley, Kramer, & Priest, 2008) found that experts rate benefit substantially higher compared to risk. The same study also found that experts differentiate between benefit and risk to the environment, to human health and societal risk (Besley et al., 2008). A study of U.S. nanoscientists suggests that experts are particularly concerned about the impact of nanotechnology on human health (Corley, Scheufele, & Hu, 2009).

An important finding is that both perceived risk and perceived benefit vary between different areas of technology application, that is, whether nanomaterials and nanotechnology is to be used in medical applications, food applications etc. (Gupta, Fischer, & Frewer, 2015; Gupta et al., 2012; Siegrist, Cousin, Kastenholz, & Wiek, 2007; van Dijk et al., 2015). Previous research suggests that several factors influence why some areas are considered to be more or less beneficial, and more or less risky. The study conducted by Van Dijk et al. (2015) indicates that experts' attitudes towards different applications is to a large extent shaped by perceived risk and benefit (van Dijk et al., 2015). However, other determinants of stakeholders' attitudes towards nanotechnology are also identified. A negative attitude to nanotechnology applications in food (compared to medical application) was not explained solely by perceived risk, but also by other factors such as understood consumer exposure, low urgency, anticipated negative consumer response, high uncertainty of risks, and a lack of a clear regulatory framework for nano-food (van Dijk et al., 2015). The study also suggests that perceptions of risk and benefit influence each other negatively (van Dijk et al., 2015): experts who have higher perception of risk have lower perception of benefit both for nanotechnology in general and for specific areas of application, suggesting that perceived benefit might be off-set by perceived risk.

Furthermore, previous studies indicate that perceived risk and perceived benefit among experts varies with educational background. The study of Berthold et al. shows that experts with a large knowledge of nanotechnology have higher risk perception (2016). This resonates with other studies finding that scientists have higher risk perception than the general public. Studies have also shown that upstream scientists (directly working with developing nanotechnology) are more prone to emphasize benefits and downplay risks, while downstream scientists (studying effects of nanomaterials) alternatively emphasize risks and downplay benefits (Powell, 2007).

Previous research on expert's views on nanotechnology shows that perceived risk and perceived benefit varies with their organizational affiliation (Beaudrie, Satterfield, Kandlikar, & Harthorn, 2013; Besley et al., 2008; Corley et al., 2009). These studies have shown differences in attitude towards nanotechnology between NGO experts, academics, industry experts and government experts (Gupta et al., 2012; Hansen, 2010; van Dijk et al., 2015). It is argued that stakeholders' view on benefit and risk is influenced by their organizational affiliation and their role in society. Van Dijk et al. (2015, p. 279) argue:

> The importance of potential benefits and risks may thus differ between stakeholders from specific groups (e.g. government, industry, NGOs) related to interest and responsibilities of these groups. Traditionally, technology developers such as scientists and industrial actors have considered themselves responsible that a newly developed technology holds benefits, while NGOs and government agencies are responsible for consideration of ethical and social issues.

The study made by Van Dijk et al. shows that there is variability between different types of expert groups whereby experts employed by an NGO had a relatively negative opinion towards nanotechnology and experts employed by industry had a more positive attitude (van Dijk et al., 2015).

Another prevalent theme in previous research on scientist and expert stakeholder views on nanotechnology is their attitude to regulation and various regulatory measures. A general finding is that risk assessments are seen as fundamental for regulation and legislation, and high perceived risk tends to correspond with a more positive attitude towards regulation. Studies of U.S. nanoscientists indicate that scientists with high risk perception were also more positive to stronger regulation (Besley et al., 2008; Corley et al., 2009). However, although Corley et al. (2009) hypothesized that scientists with higher perception of benefit with nanotechnology would support lower levels of regulation to facilitate development of nanotechnology applications, they did not find that perceived benefit had a significant impact on experts' support for regulation of nanotechnology.

Also, attitude to regulation varies with organizational affiliation, which can be explained by the different roles of organizations that experts are working within. Traditionally governmental agencies are understood to be responsible for regulation and public health safety, and environmental NGOs are understood to be responsible for the protection of the environment and consumer safety, while industry and trade organizations are expected to promote innovation and commercialization (van Dijk et al., 2015). In line with these different roles and responsibilities stakeholders have different attitudes to the development of regulations. Van Dijk et al. writes that "Trade organizations tend to use criteria that relate to proportionality and benefits to evaluate the acceptability of different regulatory options for nanotechnology, whereas environmental NGOs weigh health, environmental concerns, regulatory, legal, social and ethical risks heavily […]" (van Dijk et al., 2015, p. 279).

3. Methodology

3.1 Participants and data collection

The population of expert stakeholders engaging with issues concerning nanomaterials and nanotechnology in Sweden is not a predefined group from which a random sample can be drawn. The identification of participants for the web survey has followed a process consisting of several steps.[1] Potential experts and organizations were initially identified by using the networks of the authors, open sources such as lists of participants from conferences and workshops on nanotechnology and nanosafety, as well as previous reports on nanotechnology in Sweden (Borälv, Elg, Perez, & Svendsen, 2010; Hartmanis & Karlsson, 2005; IKEM, 2012; Perez & Sandgren, 2008). In addition, relevant experts and relevant organizations were identified using Internet searches in Google as well as Retriever. The Internet search approach was especially important for identifying industry stakeholders.

When a potentially relevant organization was identified without contact information to a specific expert, the organization was contacted via email[2] or telephone to inquire whether the organization came into contact with issues related to nanomaterials and/or nanotechnology, and if this was the case the organisation could provide contact information for relevant experts. Most organizations that responded to this request were positive to participation in the study and also provided name and contact details for relevant experts. A few organizations replied that they did not work with nanotechnology, a few additional organizations replied that they work with nanotechnology but that they did not want to be involved in the survey due to lack of time or for other unspecified reason. We do not know if the organizations that did not reply to our inquiry do not engage with issue regarding nanotechnology, or if they did not want to participate in the study.

When this preliminary list of stakeholders was compiled an email was sent to all names on the list providing information about the study, as well as asking if they could name other relevant participants within their organization, and through this procedure a few more participants were identified. A few experts responded that they had been wrongly identified and they were removed from the list. The principle of identifying the stakeholder population underlining our approach is that of self-selection; that is, the respondents identify themselves as experts working with issues concerning nanomaterials and/or nanotechnology.[3] We did not provide a definition of nanomaterials or nanotechnology in our correspondence with the experts nor in the survey. The ambition has been to identify a total sample of Swedish experts, even if some organizations and potentially relevant experts are missing, with the selection covering a large part of the current expert stakeholder community.

The final list of participants consisted of 237 people from 161 different Swedish organizations including government agencies, industry, NGOs as well as other organizations. The questionnaire was designed and administered to the participants using Qualtrics software. The participants received an email administered through Qualtrics containing information about the research-project and the survey, and they were requested to follow a link

[1] As argued by Besley et al. (Besley et al., 2008) such sampling procedures make the most sense for a specialized population such as the one explored here, although not technically a sample.

[2] All emails sent out regarding the survey were sent through the university email address of the first author of this report.

[3] In this selection, we have excluded researchers from universities unless they have their own nanotechnology companies, or have coordinating functions within the university or society.

and answer the questions in an online questionnaire. Three reminders were sent out; no incentive was offered. Data was collected between the end of January and the beginning of March 2017. A total of 167 experts from 116 different organizations participated in the survey. This makes up a response rate of 71%, which is very high compared to previous studies (e.g. Bertoldo, Mays, Poumadère, Schneider, & Svendsen, 2015; Besley et al., 2008; Gupta et al., 2013).[4] We consider the sample to be representative of a larger population of Swedish expert stakeholders working with issues concerning nanomaterials and nanotechnology.

The non-respondents were relatively evenly distributed among the different types of organizations. The final sample includes 52 respondents from industry (31.1%), 34 from government agencies (20,4%), 23 from universities (13.8%), 16 from trade organizations (9,6%), 8 from NGOs (4.8%), 6 from unions (3.6%), and 28 from various other organizations (16.8%). Further demographic information about participants is found in the first section of the result chapter. For the full list of participating organizations see **Appendix A**. Two respondents communicated that they wanted to make a joint statement from the organization they worked in, and personal information was excluded in their responses (gender, level of education etc.). Respondents were not required to answer all the questions in the questionnaire. Some questions include a "do not know" option and these answers were recoded as missing values in the calculations.

3.2 Questionnaire/measures

The questionnaire was designed to help answer the research questions of this report by mapping how the experts come into contact with issues concerning nanomaterials and nanotechnology, and inquiring into which areas of application are relevant to their organizations, their understanding of risks and benefits and their attitude to different regulatory measures. In order for the result of the survey to be comparable with previous research and previous reports the items in the questionnaire were designed to relate to previous international research on expert's and stakeholder's attitudes towards nanotechnology.

In the first section of the questionnaire the respondent was asked to provide demographic information about gender (male/female), highest completed education (primary school, secondary school, bachelor's degree, master's degree, doctoral degree or other),[5] scientific discipline (engineering, chemistry, physics, social science/humanities, toxicology, medicine/pharmacology, biology, environmental sciences, jurisprudence or other),[6] as well as rating their knowledge about nanotechnology (on a five-point scale anchored in 1=very low, and 5=very high). The respondent was also requested to indicate whether their primary place of employment was academia, industry, trade organization, union, NGO or other.[7] The respondent was asked to indicate how the organization of their primary employment came into contact with issues regarding nanotechnology from a list with multiple options (a list of the different options is provided in Figure 3). They were also asked to rate the importance of nanomaterials and nanotechnology in their organization (on a five-point scale anchored in 1=very little importance, and 5=very large importance).

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[4] The reasons behind the positive response rate are not the focus of this study, but they could possibly be explained through issues of trust in Swedish society, or possibly that personal contact was established with the experts in the work of creating the sample.
[5] If stating "other", respondent was requested to specify relevant educational level.
[6] If stating "other", respondent was requested to specify relevant disciplinary field.
[7] If stating "other", respondent was requested to specify relevant organizational affiliation.

The questionnaire asked the respondents to specify areas of nanotechnology application relevant for the organization from a list of 11 broad areas of nanotechnology application (a list of these applications is provided in Table 4 and multiple entries were possible for each respondent). These areas of nanotechnology application were selected by the authors of this report to encompass the most common areas of application. The list was composed from scientific literature, webpages of organizations and through a dialogue with industry. The respondent was asked to rate his/her knowledge of nanotechnology for these different areas of application (on a five-point scale anchored in 1=very little knowledge, and 5=very large knowledge).

The second section of the questionnaire was designed to investigate the respondents understanding of risk and benefit. The respondent was asked to rate benefits with nanomaterials and nanotechnology with respect to *human life and health*, *nature and ecosystem*, and also to *society at large* (on a five-point scale anchored in 1=very small benefits, and 5 =very large benefits). The respondent was then asked to rate benefits for the 11 different areas of application (from the list of shown in Table 4). In the same manner respondents were asked to rate risk with nanotechnology applications for *human life and health*, *nature and ecosystem* and *society at large*, as well as for the 11 areas of nanotechnology application (areas of application as shown in Table 4).

The third section of the questionnaire was designed to measure attitudes to regulation and risk management of engineered nanomaterials and nanotechnology. Attitudes to regulation were measured by asking respondents to report to what extent they agreed to 18 different statements on a five-point Likert-type scale (anchored in 1 = strongly agree, and 5 = strongly disagree). These questions were designed to measure attitudes to further regulation in general, attitudes to different regulatory measures as well as attitudes to the division of responsibility between different stakeholders (all items on regulation and risk management included in the questionnaire are found in **Appendix B**). The statements about regulation largely emerged from a literature review of previous research on attitudes to nanotechnology regulation (Besley et al., 2008; Bosso, 2016; Corley et al., 2009; Engeman et al., 2012; Hansen, 2010; Hansen & Baun, 2012; Miller & Wickson, 2015).

In the last section, the respondent was asked to evaluate 21 additional statements related to nanomaterials and nanotechnology on a five-point Likert-type scale, and these items were related to technology, risk communication and risk quality. All these items are listed in **Appendix C**. In addition to the multiple-choice questions and the statements to be rated on the Likert-type scale, the survey also included three fields for open comments where the respondent was asked if he or she wanted to add something about their own professional background, views on regulation, or if he/she had any additional comments about the issues discussed in the survey. All items included in the survey add up to some 144 variables analyzed and discussed in the report.

3.3 Analysis

The data set exported from Qualtrics software was analysed using SPSS software which provided tools for descriptive statistics and calculating means as well as correlations to identify trends in the material, to verify or reject the hypotheses, and to help answer the research questions of the report. The open-ended questions were coded using an inductive approach. Statements were clustered into three broad categories, *benefit and risk with nanomaterials and nanotechnology*, *regulation of nanomaterials and nanotechnology* and *definition of nanomaterials and nanotechnology*. The statements were coded into subcategories depending on their main argument. The results from the questionnaire were compared to existing research, and possible explanations for both converging and diverging results (in relation to the hypotheses) are discussed and presented in the report.

4. Result

4.1 The respondents and the organizations

We received 167 valid responses from expert stakeholders dealing with nanomaterials and/or nanotechnology. These experts come from different sectors in Swedish society and have different organizational affiliation (Figure 1). The greatest percentage of respondents were from industry (31,1%), followed by government agencies (20,4%), universities (13.8%), trade organizations (9.6%), NGOs (4.8%), unions (3.6%), while 16,8% of the respondents were affiliated with various other organizations. If the respondent chose the option *other* they were requested to specify organizational affiliation. According to these responses the category *other organization* includes research institutes, county councils, research funding agencies, various committees, and a science park. For a full list of participating organizations see **Appendix A**. In short, the sample consists of stakeholders associated with a variety of organizations with different roles and responsibilities in Swedish society.

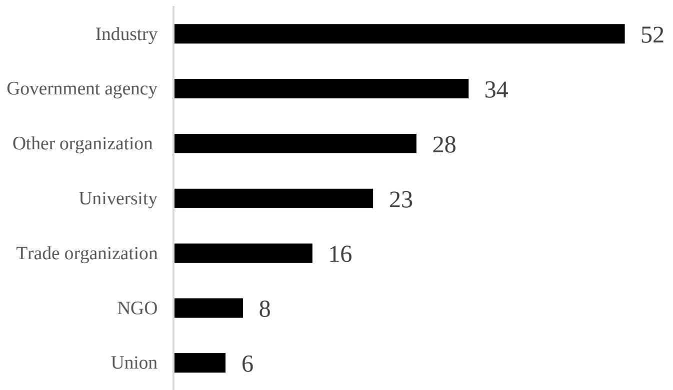

Figure 1: Distribution of respondents according to organizational affiliation

Among the respondents, N=162[8] provided information about their gender, 54 stating their gender as female (33%) and 108 stating their gender as male (67%). As shown in Table 1, 165 respondents provided information about their educational background. Over half of the respondents have a PhD degree, and one third have a master's degree. Approximately one third of the experts have a degree in engineering, and approximately one third in chemistry, but the respondents are educated in a variety of disciplines. The respondents were asked to specify their educational background if choosing *other*. Eight respondents did this and their areas of education include agriculture, material science and work environment. The information provided by the respondents on their educational background shows that they generally have a high level of education compared to the general Swedish population.

[8] As stated in the method section respondents were not required to answer all questions, the reason for this being that we wanted to increase the response rate.

Table 1: Descriptive statistics educational background (N=165)

	N	%
Highest level of education		
Doctoral degree	91	55.2
Master's degree	56	33.9
Bachelor's degree	9	5.5
Secondary school	4	2.4
Other education	5	3.0
Field of education		
Engineering	50	30.3
Chemistry	48	29.1
Physics	17	10.3
Social science/humanities	16	9.7
Toxicology	10	6.1
Medicine/pharmacology	5	3.0
Biology	5	3.0
Environmental sciences	4	2.4
Jurisprudence	2	1.2
Other	8	4.8

164 of the respondents rated their knowledge about nanomaterials and nanotechnology and the results are presented in Table 2. The mean level of self-rated knowledge about nanomaterials and nanotechnology for the whole sample is 2.99 with a standard deviation of 1.09 (1=very little knowledge, 5=very large knowledge). The self-rated knowledge differs between expert stakeholders from the different types of organization. Respondents from universities have the highest level of self-rated knowledge, followed by industry respondents. The unions, government agencies, NGOs and trade organizations have the lowest level of self-rated knowledge. If compared to Table 5 (showing how important nanotechnology is in the organization) we can see that the level of self-rated knowledge generally is higher among the type of organizations where nanotechnology is of greater importance. Females rate their knowledge slightly lower at 2.72 (SD=0.92) compared to men at 3.12 (SD=1.15).

Table 2: Self-rated level of knowledge about nanomaterials and nanotechnology distributed by organizational affiliation. Table includes information about number of respondents and standard deviation.

Organizational affiliation	*N*	*Self-rated level of knowledge*[a]	*Std. Deviation*
Government agency	33	2.58	0.97
Industry	52	3.17	1.18
Trade organization	15	2.67	0.72
Union	6	2.50	0.55
NGO	8	2.63	0.74
University	23	3.57	1.24
Other organization	27	3.07	1.04
Total	164	2.99	1.09

[a] For measuring self-rated knowledge participants were asked to rate their knowledge about nanomaterials and nanotechnology on five-point scale, anchored in 1 very little knowledge and 5 very large knowledge.

The self-rated level of knowledge about nanomaterials and nanotechnology distributed over the respondents' disciplinary background is presented in Table 3. Respondents with an educational background in physics have the highest level of self-rated knowledge about nanomaterials and nanotechnology, and those with an educational background in environmental science have the lowest level of self-rated knowledge.

Table 3: Self-rated level of knowledge about nanomaterials and nanotechnology distributed by educational background.

Educational background	*N*	*Self-rated knowledge*[b]	*Std. Deviation*
Engineering	49	2.96	1.06
Medicine/pharmacology	5	2.40	0.55
Chemistry	48	3.06	1.08
Physics	17	4.12	0.93
Biology	5	2.60	0.55
Toxicology	10	3.00	0.94
Environmental sciences	4	2.00	0.82
Jurisprudence	2	2.50	0.71
Social science/humanities	16	2.25	0.86
Other	8	3.13	1.25
Total	164	2.99	1.09

[b] For measuring self-rated knowledge participants were asked to rate their knowledge about nanomaterials and nanotechnology on a five-point scale, anchored in 1 very little knowledge and 5 very large knowledge.

The self-rated level of knowledge for the different areas of application among the different expert stakeholders is shown in Table 4. The largest level of knowledge is about coatings, materials and material production. The lowest level of knowledge about nanotechnology application was found in agriculture and food, packaging and catalysts and filters. If compared to Figure 4 we can observe that there is a general trend that knowledge is higher for the areas of application relevant to most organizations. This is however not a perfect covariance and it is possible to assume that knowledge about one area also affects knowledge within another area using similar techniques, and that nanotechnology applications within some areas are less complex than others.

Table 4: Self-rated level of knowledge for the different areas of application for nanomaterials and nanotechnology among all expert stakeholders in the survey.

Area of application	*N*	*Self-rated level of knowledge*	*Std. Deviation*
Medicine and medical care	159	2.04	1.08
Environmental and energy technology	157	2.13	1.03
Measuring instruments and sensors	155	2.05	1.07
Cosmetics and hygiene products	158	1.91	0.96
Agriculture and food	153	1.67	0.77
Packaging	154	1.79	0.97
Electronics	155	2.08	1.19
Coatings	158	2.58	1.27
Material and material production	157	2.57	1.26
Catalysts and filters	152	1.87	1.01
Paint	156	1.99	1.04

All respondents were affiliated with organizations working with issues concerning nanomaterials and/or nanotechnology, but the extent of importance differed. 166 respondents provided information on the importance of nanotechnology in the organization (Figure 2). 21 state that nanomaterials and nanotechnology are of very little importance in the organization, 52 state that they are of little importance, 45 state that they have a rather high importance, 26 state that they have large importance and 22 state that they have very large importance in the organization. As shown in Table 5 the importance of nanotechnology varies with organizational affiliation. It has the greatest importance for respondents at university and industry, and the lowest importance for government agencies and trade organizations.

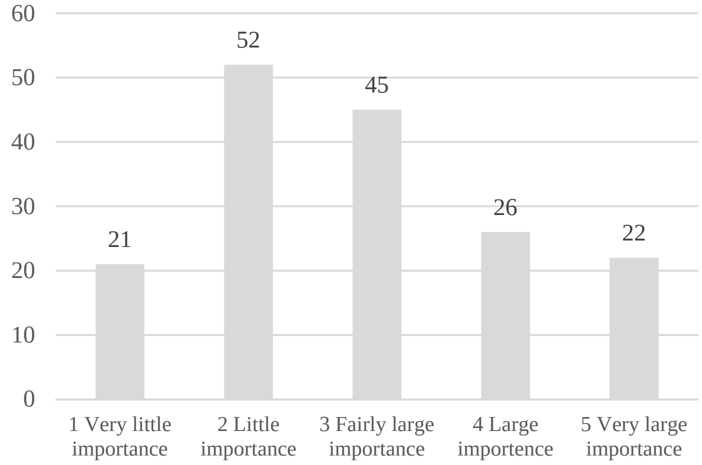

Figure 2: Importance of nanomaterials and nanotechnology in the organization respondent is associated with.

Table 5: Importance of nanomaterials and nanotechnology in organization distributed by organizational affiliation.

Organizational affiliation	*N*	*Importance of nanomaterials and nanotechnology in the organization*[c]	*Std. Deviation*
Government agency	33	2.24	1.06
Industry	52	3.31	1.31
Trade organization	16	2.31	0.95
Union	6	2.83	0.75
NGO	8	2.38	0.92
University	23	3.39	1.27
Other organization	28	2.75	1.04
Total	166	2.86	1.22

[c] For measuring importance of nanomaterials and nanotechnology in the organization the respondent was asked to rate the importance on five-point scale, anchored in 1 very little importance and 5 very large importance.

The respondent was requested to state how the organization he or she is affiliated with is working with issues relating to nanomaterials and nanotechnology from the list in Figure 3 (multiple answers were possible). 166 respondents provided information and the results show that organizations come into contact with issues concerning nanomaterials and nanotechnology in many different ways, including, research and research funding, risk assessment, product development, as well as regulation and legislation. If the respondent chose the category *other*, they were requested to specify how the organization comes into contact with issues concerning nanomaterials and nanotechnology, and according to these answers the category *other* includes waste disposal, education, analysis, building laboratories, food safety, ethical questions as well as standardization. In other words, the question of nanomaterials and nanotechnology engages expert stakeholders in several different ways, including but not limited to research, product development, risk assessment and regulation.

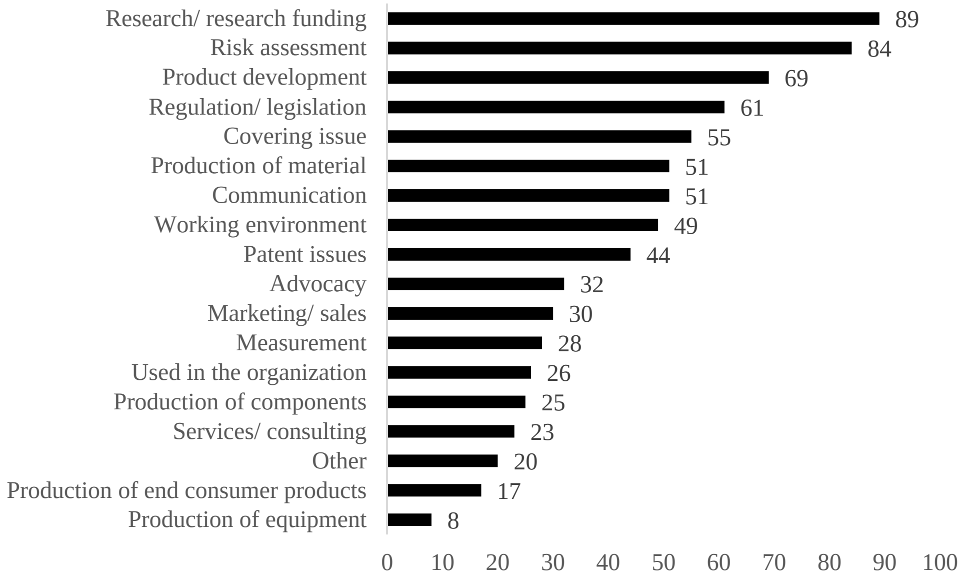

Figure 3: Areas in which organizations engage with issues related to nanomaterials and/or nanotechnology. Multiple entries were possible for each respondent.

The respondents were also requested to state the areas of application relevant for the organization they worked within from a list constructed by the authors of this report (multiple entries were possible for each respondent). The result is presented in Figure 4 and shows that all areas of nanotechnology application included in the questionnaire were relevant for at least part of the population of expert stakeholders. The areas of nanotechnology application relevant to the largest number of organizations were material and material production (N=82) as well as coatings (N=77). The areas of nanotechnology application relevant to the smallest number of organizations were agriculture and food (N=22), and cosmetics and hygiene products (N=25). If the respondents ticked *other organization*, they were requested to specify the other area(s) of nanotechnology application relevant to the organization, and their responses include vehicles, military defense, sealing products and chemicals. A few organizations stated that distinctions between different nanotechnology applications were not relevant for their engagement with nanomaterials and/or nanotechnology.

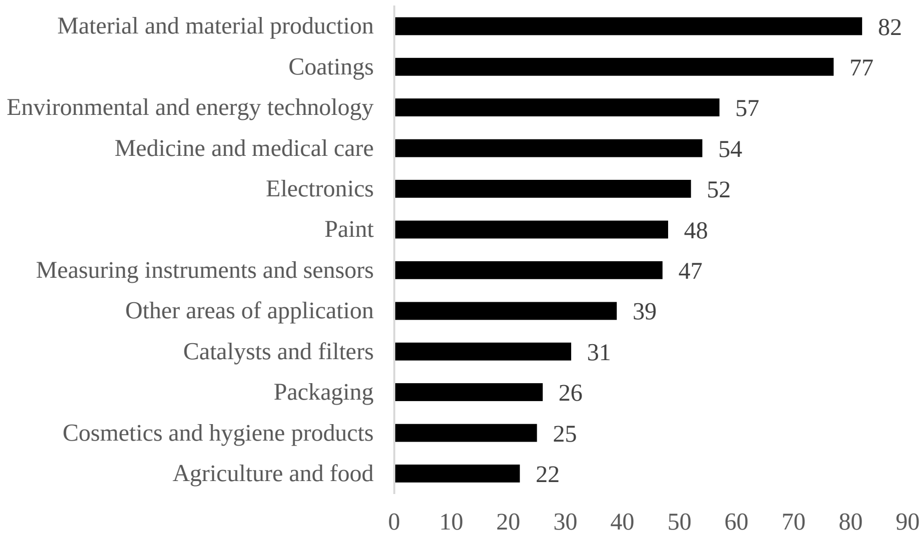

Figure 4: Areas of application relevant for the organization associated with the respondents. Multiple entries were possible for each respondent.

<u>*Summary*</u>

The aim of this first introductory part of the result-section has been to give an overview of the field of Swedish expert stakeholders working with nanomaterials and/or nanotechnology, and not to evaluate the hypotheses of the report. To summarize, the respondents are associated with different organizations in Swedish society from within industry, government and civil society and they come into contact with issues of nanotechnology to larger or lesser extent. The expert stakeholders work with nanomaterials and nanotechnology in different ways including but not limited to regulation, production, risk assessment, product development, regulation, education and research. They have an expert role in society, but do not necessarily have a profound knowledge of nanomaterials and nanotechnology. In general, they are well educated, far above the average Swedish population; over half of the respondents hold a PhD (compared to 1.28 % of the Swedish population in ages 25-64). Diverse areas of nanotechnology application were relevant to the organizations, and the broad categories of nanotechnology application constructed for this survey (Figure 4) were confirmed to encompass most areas of application relevant to Swedish organizations. We will now proceed by presenting the results from the experts stakeholders' perception of risks and benefits with nanotechnology.

4.2 Perceived risk and perceived benefit with engineered nanomaterials and nanotechnology

4.2.1 Perceived risk and benefit for nature, humans and society

The respondents were requested to rate perceived risk and perceived benefit with nanotechnology both in general in three contexts of values at stake (human life and health, nature and ecosystem, and society at large), and more specifically with regard to a number of categories of nanotechnology application. 161 respondents provided information on benefits with nanotechnology for the three values at stake (Table 6). For the entire population of respondents there is high perceived benefit with nanomaterials and nanotechnology. The scores are highest for *society at large* (3.99), followed by *human life and health* (3.91). Benefit to *nature and ecosystem* is rated lower at 3.24. Differences in ratings can possibly indicate that respondents foresee high benefits within medicine, but to a lesser extent foresee nanotechnology innovation as a solution to major environmental problems. The computed mean for benefit for human life and health, benefit for nature and ecosystems as well as benefit for society at large is 3.73 for the entire sample with a standard deviation of 0.89 (this will be used as the benefit index to compare perceived benefit between categories of stakeholders). The fact that the respondents rate benefits for *society at large* higher than benefits for *human life and health* and for *nature and ecosystem* suggests that the respondents see other societal benefits such as economic development.

Table 6: Perceived risk and perceived benefit with nanomaterials and nanotechnology for entire sample of Swedish expert stakeholders.

	Benefit	*Std. deviation*	*Risk*	*Std. deviation*
Benefit and risk with nanomaterials and nanotechnology for *human life and health*	3.91	0.88	2.77	0.92
Benefit and risk with nanomaterials and nanotechnology for *nature and ecosystems*	3.24	1.27	2.88	1.05
Benefit and risk with nanomaterials and nanotechnology for *society at large*	3.99	0,88	2.60	0.90
Mean (index for benefit[d] and risk[e])	3.73	0.89	2.75	0.89

[d] The variable for general perceived benefit with nanomaterials and nanotechnology is the computed mean of perceived benefit for human life and health (1=very small benefit, 5=very large benefit), benefit for nature and ecosystem (1=very small benefit, 5=very large benefit) and benefit for society at large (1=very small benefit, 5=very large benefit), and thus a value number between 1 and 5, where a high number indicates high perceived benefit.

[e] The variable for general perceived risk with nanomaterials and nanotechnology is the computed mean of perceived risk for human life and health (1=very low risk, 5=very high risk), risk for nature and ecosystem (1=very low risk, 5=very high risk) and risk for society at large (1=very low risk, 5=very high risk), and thus a value number between 1 and 5, where a high number indicates high perceived risk.

160 respondents provided information on perceived risk with nanotechnology for different values at stake (Table 6). Risk for *nature and ecosystem* is rated higher compared to risk to *human life and health*. Different ratings indicate that respondents in general make a conceptual differentiation between different types of risk. **Hypothesis B** which states that there is a difference in risk

perception depending on the overarching value at stake: the environment, human life and health, and society at large can thus be confirmed. However, **Hypothesis C** stating that experts perceive larger risk for human life and health compared to environmental risk must be rejected.

Comparing the index for perceived risk with index for perceived benefit, risk is rated lower at 2.75 (SD=0.89) compared to benefit at 3.73 (SD=0.89). This means we can confirm **Hypothesis A** that experts rate benefit higher than risk. Comparing estimated risk with estimated benefit we can see that benefit exceeds risk for both *human life and health* and *nature and ecosystem*, as well as for *society at large*. There is a statistically significant negative correlation between perceived risk for nanotechnology and perceived benefit for nanotechnology.[9] This is a small but statistically significant correlation and implies that perception of risk and perception of benefit is connected. **Hypothesis D** can thus be confirmed to be true.

4.2.2 Risk and benefit dependent on area of nanotechnology application

The respondents were also requested to rate benefit and risk with nanomaterials for each area of nanotechnology application (Table 7). The mean rated benefit for all areas of application is 3.92 (SD=0.66), i.e. close to "large benefits". However, there are large differences between perceived benefits for different areas of application. The largest overall perceived benefit is for *coatings* (4.42), *electronics* (4.42), and *material and material production* (4.40), compared to lowest perceived benefits for *cosmetics and hygiene products* (2.60) and *agriculture and foods* (2.71). There might be several explanations as to why benefit is rated differently for different areas of application by Swedish expert stakeholders. Previous research suggests perceived benefit with nanotechnology applications might be offset by perceived risk (Gupta et al., 2015). But as seen in Table 8 the only areas of nanotechnology application where there is a significant correlation between perceived risk and perceived benefit is cosmetic and hygiene products, agriculture and food, as well as electronics, and perceived risk can only partially explain how experts perceive benefit even for these areas of application. Additional research is needed to understand how expert stakeholders form their judgment on how beneficial nanomaterials and nanotechnology are understood for different areas of application.

The open comments in the questionnaire did not provide any explanations as to why some applications are considered more beneficial than others. It can be assumed that many factors influence how the sample of expert stakeholders rate benefit. It is reasonable to assume that perceived benefit is influenced by how beneficial the area of application is considered to be for society at large. Nanotechnology applications within medicine might for this reason be rated as more beneficial compared to applications within cosmetics. Furthermore, it is reasonable to assume that whether or not there are already existing well-functioning applications positively influences perceived benefits, or if possible beneficial applications are foreseen to be available in the near future. Such reasoning might explain why medicine is considered less beneficial compared to coatings, materials and electronics, because there are currently few applications within medicine and medical care. Even if medicine as a field is considered useful, there are few current applications, and commercialization may be restricted because of the strict regulation of the field (which is also suggested by two respondents in the open comments in the questionnaire). Another factor likely to influence the understanding of benefits within an area of application is the relative potential improvement nanotechnology is understood to convey.

[9] r = -0.249, correlation is significant at the 0.01 level or higher.

Table 7: Perceived benefit and perceived risk with nanomaterials and nanotechnology for different areas of application.

Area of application	*Perceived benefit* [f]	*Standard deviation*	*Perceived risk* [g]	*Standard deviation*	*Difference between perceived benefit and perceived risk* [h]
Medicine and medical care	4.13	0.81	2.37	0.89	1.76
Environmental and energy technology	3.94	0.97	2.32	1.02	1.62
Measuring instruments and sensors	4.28	0.76	1.76	0.73	2.52
Cosmetics and hygiene products	2.60	1.10	3.30	1.07	-0.70
Agriculture and food	2.71	0.96	3.07	1.06	-0.36
Packaging	3.34	1.15	2.32	0.96	1.02
Electronics	4.42	0.81	2.00	0.87	2.42
Coatings	4.42	0.74	2.41	1.02	2.01
Material and material production	4.40	0.78	2.52	0.99	1.88
Catalysts and filters	4.36	0.76	2.24	0.91	2.12
Paint	3.95	0.88	2.76	1.05	1.19
Total	3.92	0.66	2.50	0.79	1.42

[f] The variable for general perceived benefit with nanomaterials and nanotechnology is the computed mean of perceived benefit for human life and health (1=very small benefit, 5=very large benefit), benefit for nature and ecosystem (1=very small benefit, 5=very large benefit) and benefit for society at large (1=very small benefit, 5=very large benefit), and thus a value number between 1 and 5, where a high number indicates a high perceived benefit.

[g] The variable for general perceived risk with nanomaterials and nanotechnology is the computed mean of perceived risk for human life and health (1=very low risk, 5=very high risk), risk for nature and ecosystem (1=very low risk, 5=very high risk) and risk for society at large (1=very low risk, 5=very high risk), and thus a value number between 1 and 5, where a high number indicates high perceived risk.

[h] This figure is the variable for perceived benefit minus variable for perceived risk. A positive number indicates perceived benefit exceeds perceived risk and a negative number indicates perceived risk exceeds perceived benefit.

Perceived risk varies for the different areas of nanotechnology application (Table 7). The respondents generally perceive low risk and the mean perceived risk for all areas of application is 2.50 (SD=0.79). The experts perceive the highest risk with nanotechnology application in *cosmetics and sanity products* (3.30) and *agriculture and food* (3.07) compared to lowest perceived risks for *measuring instruments and sensors* (1,76) and *electronics* (2,00). Why experts rate risk differently for different areas of nanotechnology application might have several reasons. It is possible that perceived risk might be offset by perceived benefit, but as discussed above this can only be a partial explanation for some areas of application (because it only correlates with perceived benefit for a few areas of application Table 8). This means that other factors determine how expert stakeholders evaluate risk for different nanotechnology applications.

In the open text responses in the survey one respondent emphasized that rating of risk for the different areas of application is dependent on toxicity of materials used within a specific area, as well as exposure, and that applications within electronics from this perspective could be seen as less risky compared to hygiene products where the crossover of nanoparticles into the environment is harder to control. Many experts have a background within science, therefore toxicity and perceived exposure is likely to be influential for how experts rate risk for different areas of nanotechnology application. The areas of application considered most risky, agriculture and food, and cosmetics and hygiene are areas of application that involve body exposure. Also, the three areas of application considered most risky (agriculture and food, cosmetics and hygiene products, and paint) are all areas of application using relatively large quantities of nanoparticles with a higher probability of crossover into the environment. This finding corresponds to the result by Gupta et al. (2012) that experts judged the responses in society to nanotechnology to be driven by perceived benefit, and "how 'real' and physically close to the end-user these applications are perceived to be" (p. 857).

There is also a tendency among the respondents to rate risk for the diverse areas of application differently depending on whether the application is relevant within their organization: respondents rate risk lower if they also said that this application is relevant within the organization. This result is aligned with the risk literature, arguing that knowledge generally give a higher sense of control, and consequently lower risk perception (Slovic, 2016). This could also partly explain why cosmetics and hygiene products as well as food and agriculture are ranked as riskier, as these are also the applications least relevant in the organizations (Figure 4).

Table 8: Correlation between perceived benefit and perceived risk for the different areas of nanotechnology application.

Area of application	Pearson Correlation	Sig. (2-tailed)
Medicine and medical care	-0,016	0,865
Environmental and energy technology	0,032	0,760
Measuring instruments and sensors	0,000	1,000
Cosmetics and hygiene products	-0,379	0,000**
Agriculture and food	-0,213	0,053*
Packaging	-0,179	0,114
Electronics	-0,175	0,083*
Coatings	-0,092	0,331
Material and material production	-0,037	0,706
Catalysts and filters	-0,072	0,512
Paint	0,002	0,987

* Correlation is significant at the 0.1 level or higher.
** Correlation is significant at the 0.01 level or higher.

There are differences in how the respondents rate risk as well as benefit depending on the area of application; both **Hypothesis E** and **Hypothesis F** are therefore confirmed. The largest difference between perceived risk and perceived benefit is for *measuring instruments and sensors* (2,52) as well as *electronics* (2,42). *Cosmetics and hygiene products* as well as *agriculture and food* have a negative value, meaning that perceived risk exceeds perceived benefit, so even if benefit outweighs risk in an overall rating, risk is rated higher compared to benefit for two areas of application. **Hypothesis G** which states that experts would rate benefit higher for all areas of nanotechnology applications included in the survey must therefore be rejected. In accordance with **Hypothesis H** experts see applications within food as risker and less beneficial compared to applications within medicine.

4.2.3 Perception of risk and benefit dependent on organizational affiliation

As revealed in Table 9, perceived risk and perceived benefit vary with organizational affiliation. University experts (3.88) and industry experts (3.84) perceive highest benefit while experts from trade organizations (3.45) and NGOs (3.54) perceive the lowest benefit. It is reasonable to assume that difference in perceived benefit is influenced by the societal role of the organization, and that high perceived benefit for university and industry can be understood from their role as working with innovation and commercialization. The trend of rating benefits for *human life and health* and *society at large* compared to benefits to *nature and ecosystem* is persistent for experts from the different organizations except for trade unions who make similar ratings for benefits within the different areas.

There are also differences in perceived risk between experts from the different types of organization. There is a greater difference in how the different experts estimate risk compared to how they estimate benefit. Experts from NGOs have the highest risk perception (3.62) followed by union experts (3.14), experts working for trade organizations perceive the lowest risk (2.44), followed by experts from government agencies (2.61). In line with **Hypothesis N**, experts from trade organizations have a low risk perception, while experts affiliated with NGOs have a higher risk perception. This can be understood through their different roles in society. NGOs engage among other things in work to promote environmental safety and consumer safety and can thus be expected to be more concerned with risk issues with nanotechnology. The role of the trade organizations, on the other hand, is to promote industry and commercialization. However, contrary to **Hypothesis N** both industry and government agencies rate risk similarly, close to the average perceived risk for the entire sample. And we must thus reject **Hypothesis N**. There are several possible reasons for this. One reason could be that nanotechnology companies are more engaged in the topic, while it is less relevant for government experts (Table 5). Another reason could possibly be that corporative tradition in Swedish society has often emphasized common goals and shared responsibilities (Löfstedt, 2005).

Table 9: General perceived benefitand general perceived risk distributed by organizational affiliation.

Organizational affiliation	*Perceived benefit* [i]	*Std. Deviation*	*Perceived risk* [j]	*Std. Deviation*
Government agency	3.66	0.82	2.61	0.77
Industry	3.84	0.89	2.66	0.92
Trade organization	3.45	1.06	2.44	0.98
Union	3.67	1.08	3.14	0.50
NGO	3.54	0.94	3.62	1.03
University	3.88	1.04	2.90	0.86
Other organization	3.71	0.73	2.75	0.88
Total	3.73	0.89	2.75	0.89

[i] The variable for general perceived benefit with nanomaterials and nanotechnology is the mean of perceived benefit for human life and health (1=very small benefit, 5=very large benefit), benefit for nature and ecosystem (1=very small benefit, 5=very large benefit) and benefit for society at large (1=very small benefit, 5=very large benefit), and thus a value between 1 and 5.
[j] The variable for general perceived risk with nanomaterials and nanotechnology is the mean of perceived risk for human life and health (1=very low risk, 5=very high risk), risk for nature and ecosystem (1=very low risk, 5=very high risk) and risk for society at large (1=very low risk, 5=very high risk), and thus a value between 1 and 5.

4.2.3 The influence of gender, self-rated knowledge and educational background on perceived risk and benefit

Perceived risk and perceived benefit vary across a number of variables. There is no statistically significant connection between gender and perceived risk, there is however a statistically significant difference in general perceived benefit, where women rate benefits lower 3.48 (SD=0.81) compared to men 3.84 (SD=0.90).[10] Self-rated knowledge does not correlate significantly with perceived risk, however self-rated knowledge is significantly correlated to perceived benefit[11]. Respondents with a high self-rated knowledge are also more prone to rating benefits of nanotechnology higher.

Perception of risk and benefit also vary according to the disciplinary field as shown in Table 10. Experts with an education in environmental science have the lowest perception of benefit of nanomaterials and nanotechnology (2.78), while experts with a background in physics have higher overall rating of benefits at 4.16. As is also shown in Table 10, there are differences in how experts rate risk dependent on the expert's disciplinary field. Experts with an education in medicine give an overall rating of risk at 4.00 while experts with an educational background in biology give an overall rating of risk at 2.27. Educational background seems to influence both perception of risk and perception of benefit. We can conclude that ratings of risk and benefit vary with educational background as hypothesized (**Hypothesis I**). The distribution of different fields of education however is not aligned with **Hypothesis J**, stating that upstream scientists evaluate risk lower compared to downstream scientists; **Hypothesis J** must thus be rejected.

[10] An independent sample t-test shows a significant difference at the 0,05 level or higher.
[11] r=0.335, correlation is significant at the 0.01 level or higher.

Table 10: General perceived benefit and general perceived risk distributed on respondents' educational background.

Educational background	*Perceived benefit*[k]	*Std. Deviation*	*Perceived risk*[l]	*Std. Deviation*
Engineering	3.76	0.92	2.77	0.96
Medicine/pharmacology	3.42	0.69	4.00	1.00
Chemistry	3.66	0.89	2.68	0.84
Physics	4.16	0.82	2.65	0.85
Biology	3.80	1.10	2.27	0.72
Toxicology	3.92	0.73	2.60	0.97
Environmental sciences	2.78	1.02	2.78	0.38
Jurisprudence	3.08	0.59	3.00	0.00
Social science/humanities	3.61	0.92	2.48	0.53
Other	3.54	0.83	3.61	1.04
Total	3.73	0.89	2.75	0.90

[k] General perceived benefit with nanomaterials and nanotechnology is measured as the mean of perceived benefits for human life and health (1=very small benefit, 5=very large benefit), benefit for nature and ecosystem (1=very small benefit, 5=very large benefit) and benefit for society at large (1=very small benefit, 5=very large benefit).

[l] General perceived risk is measured as the mean of perceived risk for human life and health (1=very low risk, 5=very high risk), risk for nature and ecosystem (1=very low risk, 5=very high risk) and risk for society at large (1=very low risk, 5=very high risk).

Summary

In this section we have analysed how Swedish expert stakeholders rate risk and benefit, and discussed factors that influence how they make these estimations. As hypothesized in the introduction the experts rate benefit relatively high compared to risk, and **Hypothesis A** can be confirmed to be true. As predicted in **Hypothesis B**, the Swedish experts seem to differentiate between values at stake and rate *risk to the environment*, *risk to human health*, and *risk to society at large* differently. However, in contrast to what was predicted in **Hypothesis C** experts rate risk to the environment higher compared to human life and health. The experts also differentiate between benefit for the environment, for human health, and for society at large. **Hypothesis D** predicting that risk and benefit will influence each other negatively, so that experts more prone to see benefits with nanomaterial will be less prone to see risk, was also confirmed.

Perceived risk as well as perceived benefit vary with area of nanotechnology application, and thus **Hypothesis E** and **Hypothesis F** are confirmed. Experts rated benefits higher compared to risk for all areas of nanotechnology application, except for nanotechnology applications in *foods and agriculture*, and *cosmetics and hygiene products*. We must thus reject **Hypothesis G** (stating that respondents would rate benefit higher compared to risk for all areas of nanotechnology application). In line with **Hypothesis H** experts understood food applications as less beneficial and riskier compared to applications within medicine. This study included several nanotechnology applications to be rated, and as will be discussed more thoroughly in the discussion section there are many possible reasons as to why some areas of application are understood as more or less beneficial or more or less risky.

The study has shown that there are differences in how experts rate benefit and risk dependent on organizational affiliation. The differences in perceived benefit were rather small, but the differences in how experts from different organizations rated risk were large. Aligned with **Hypothesis N** NGO respondents rated risk high, while trade organizations made a low rating. However, contrary to **Hypothesis N**, industry and government agencies made similar ratings of risk, at approximately the average for the sample, and **Hypothesis N** must thus be rejected. There are also differences in how experts rate risk and benefit depending on their educational background, thus **Hypothesis I** is confirmed to be true. However, the result is not in agreement with **Hypothesis J** (stating that upstream scientists evaluate risk lower compared to downstream scientists).

4.3 Regulation and legislation

4.3.1. General attitude to regulation

The questionnaire included a number of statements about regulation of nanomaterials and nanotechnology in regards to general attitude to further regulation, and in regards to specific regulatory measures. The respondents were asked to rate each statement on a 5-point Likert-type scale anchored in 1=Strongly disagree, and 5=Strongly agree (all items regarding regulation and risk-management are found in **Appendix B**). When asked to indicate to what extent they agreed with the statement "the regulation of nanomaterials and nanotechnology today is fully sufficient" (1=Strongly disagree, 5=Strongly agree), 58% of the respondents chose the two lowest scoring items, and can thus be considered to disagree with this statement and being supportive of further regulation. 17 % chose the two highest scoring items – and can thus be considered to agree with the statement and not being supportive of further regulation. Only 4% of the respondents chose the highest scoring alternative. In other words, the general attitude among the respondents is that current legislation and regulation of nanomaterials and nanotechnology is insufficient. The inverted value of the answer to the above-mentioned statement will be used in this report as an index of how supportive the respondents are to further regulations, having the mean value of 3.66 (SD=1.14), for the entire sample of experts.

In the open-ended text-responses seven respondents strongly propagated for the need of further regulation of nanomaterials and nanotechnology, while other respondents (N=3) emphasize that current regulation is sufficient. In accordance with previous research there are disagreements over definitions of nanomaterials, and over the applicability of *nano* as an over-arching framework for risk assessment and regulation. Five respondents in the open-ended comments questioned the definition of nanomaterials, and one respondent explicitly questioned whether nanotechnology and nanomaterial could be used as an overarching framework for risk assessment and regulation. In other words, a majority of the expert stakeholders believe that more regulation is needed, and that *nano* is a relevant framework for risk assessments and regulation, but there is also some disagreement among the experts on this issue.

There is a statistically significant positive correlation between perceived risk with nanomaterials and nanotechnology and a positive attitude towards further regulation (r=0,634).[12] High perceived risk is a strong determinant for a positive attitude to further regulation of nanomaterials and nanotechnology (perceived risk explains 40% of the variance in stakeholders' attitudes to further regulation). We can thus confirm **Hypothesis K**, stating that risk perception is connected to being supportive of further nanotechnology regulation. There is also a statistically significant, although negative correlation[13] between perceived benefit and attitudes to further regulation. This means that **Hypothesis L** must be rejected, which predicted that perception of benefit is not connected to support of further regulation.

The items on regulation to be rated by the respondents on the Likert-type scale provided some more information on the respondents' attitudes to regulation. These answers show that they have a negative attitude to public involvement in regulation of nanomaterials and nanotechnology (2.25, SD=1.17). There is a general agreement that regulation should be based on science (4.66, SD=0.63).

[12] Correlation is significant at the 0.01 level or higher
[13] r=-0.301, correlation is significant at the 0.01 level or higher

The precautionary principle has a large degree of support among the respondents 3.99 (SD=1.00). A strong support for regulation based on science, and a low support for public involvement can possibly be understood as relating to the technocratic tradition in the Swedish state and a high level of public trust in institutions (Löfstedt, 2005).

4.3.2 Attitude to different regulatory measures

The questionnaire included items with statements regarding different measures for regulation of nanomaterials and nanotechnology. As can be seen in Table 11 there are differences in the support for different regulatory measures. Among the respondents there is a relatively strong support for selective prohibition, while a low degree of support for taxation and self-regulation. There is a high standard deviation for both labelling and selective prohibition, and 14 experts strongly disagree with the statement that selective prohibition is an applicable regulatory measure, and 35 experts strongly disagree that labelling is an applicable regulatory measure. In other words, there is disagreement among respondents about the appropriate tools for regulating nanomaterials and nanotechnology.

Table 11: Respondents answers to questions on their attitude to different regulatory measures

	N	Mean	SD	1	2	3	4	5	Balance[m]
Attitude to further regulation[n]	154	3.66	1.14	6	20	39	44	45	40.9
Self-regulation[o]	156	2.01	1.02	61	48	36	7	4	-62.8
Labelling[p]	155	2.90	1.39	35	27	37	30	26	-3.9
Selective Prohibition[q]	151	3.40	1.31	14	27	35	34	41	22.5
Taxation[r]	149	1.53	0.85	95	36	14	1	3	-85.2

[m] The balance value is the percentage of respondents who chose one of the two lowest values, minus the percentage of respondents who chose one of the two highest values. In other wording, the balance value is a number between -100 and 100. A strong positive number indicates a general supportive attitude, whereas a strong negative number indicates a low general level of support to the regulatory measure.

[n] The variable for general attitude to regulation is the inverted value of the answer to "The regulation of nanomaterials and nanotechnology today is fully sufficient." (1=Strongly disagree, 5=Strongly agree).

[o] The variable for attitude to self-regulation as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Companies should be responsible for formulating regulation in their field of business." (1=Strongly Disagree, 5=Strongly Agree).

[p] The variable for attitude to labeling as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Mandatory labeling of all products containing nanomaterials and nanoparticles is required" (1=Strongly disagree, 5=Strongly Agree).

[q] The variable for attitude to prohibition as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Certain nanomaterials and nanoparticles should be banned entirely in products." (1=Strongly disagree, 5=Strongly agree).

[r] The variable for attitude to taxation as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Excise taxes are an appropriate way of controlling risks with nanomaterials and nanotechnologies." (1=Strongly disagree, 5=Strongly agree).

4.3.3 Differences in views on regulation depending on organizational affiliation

Differences in support for further regulation vary with the respondents' organizational affiliation (Table 12), and **Hypothesis M** can thus be confirmed. As expected from **Hypotheses O** regulations have highest support among NGO respondents, and lower support among trade organizations respondents. Somewhat surprisingly there are no differences in support for regulation between government experts and industry experts. This means that we have to reject **Hypothesis O**, stating that NGO and government stakeholder experts would be more supportive of further regulations compared to trade organization and industry. The divergent result from the hypothesis can have several explanations. As pointed out by two respondents in the open-ended comments in the questionnaire there is not a strict opposition between commercialization and regulation, and commercialization can be supported by international standardized regulation. In other words, lack of regulation (and especially uncertainty about future regulation) is not necessarily favourable for industry. The similar attitude among industry experts and government experts can also be interpreted in a corporatist tradition of Swedish society and as an expression for a sense of shared responsibilities.

Table 12: Attitude to further regulation of nanomaterials and nanotechnology distributed by organizational affiliation

Organizational affiliation	*N*	*Support for further regulation*[s]	*Std. Deviation*
Government agency	31	3.52	1.09
Industry	50	3.50	1.13
Trade organization	16	3.19	1.38
Union	6	4.17	0.41
NGO	8	4.00	1.41
University	19	4.11	1.10
Other organization	24	3.92	1.02
Total	154	3.66	1.14

[s] The dependent variable for attitude to regulation is the inverted value of the answer to "The regulation of nanomaterials and nanotechnology today is fully sufficient." (1=strongly agree, 5=strongly disagree), the variable is a number between 1 and 5 and a high value indicates a strong support for further regulations.

There are differences in how supportive experts are of different regulatory measures as can be seen in Table 13. Even though they are not more in favour of further regulation in general, industry experts are more supportive of self-regulation compared to government experts. NGO experts and union experts are more supportive to labelling compared to other stakeholders.

Table 13: Attitude to different regulatory measures distributed by organizational affiliation

	Self-regulation[t]	Labelling[u]	Bans[v]	Taxation[w]
Government agency	1.81	2.90	3.14	1.53
Industry	2.30	2.40	3.14	1.33
Trade organization	2.38	2.81	3.71	1.57
Union	1.83	3.50	4.17	1.80
NGO	1.63	3.50	4.25	2.25
University	1.74	3.53	3.79	1.84
Other organization	1.81	3.15	3.32	1.38
Total	2.01	2.90	3.40	1.53

[t] The variable for attitude to self-regulation as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Companies should be responsible for formulating regulation in their field of business." (1=Strongly Disagree, 5=Strongly Agree).
[u] The variable for attitude to labeling as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Mandatory labeling of all products containing nanomaterials and nanoparticles is required" (1=Strongly disagree, 5=Strongly Agree).
[v] The variable for attitude to prohibition as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Certain nanomaterials and nanoparticles should be banned entirely in products." (1=Strongly disagree, 5=Strongly agree).
[w] The variable for attitude to taxation as a measure to regulate nanomaterials and nanotechnology is the mean value of the answer to the question "Excise taxes are an appropriate way of controlling risks with nanomaterials and nanotechnologies." (1=Strongly disagree, 5=Strongly agree).

As discussed above experts generally have a negative attitude towards public involvement, there is however a difference between different stakeholders (Table 14). Expert stakeholders from industry and trade organizations are least supportive, while expert stakeholders from unions and NGOs are more supportive to public involvement.

Table 14: Support for public involvement in regulation of nanotechnology distributed by organizational affiliation.

Organizational affiliation	*N*	*Support for public involvement in the regulation of nanotechnology*[x]	*Std. Deviation*
Government agency	31	2.39	1.17
Industry	50	1.82	0.96
Trade organization	15	1.73	0.96
Union	6	3.17	1.33
NGO	8	3.25	0.71
University	19	2.53	1.26
Other organization	25	2.48	1.26
Total	154	2.25	1.17

[x] This figure is the mean value of the answer to the question "Regulation of nanomaterials and nanotechnology should take citizens' values and opinions into account" (1=Strongly disagree, 5=Strongly agree).

As discussed above, the respondents are generally supportive of the precautionary principle. This is true for all stakeholders, but there are also differences based on organizational affiliation (Table 15) where experts working in trade organizations are less supportive of the precautionary principle. Experts from all different types of organizations support the idea that regulation should be based on science.

Table 15: Support for the precautionary principle distributed by organizational affiliation.

Organizational affiliation	*N*	*Support for the precautionary principle*[y]	*Std. Deviation*
Government agency	31	4.10	0.94
Industry	50	3.82	1.04
Trade organization	15	3.53	1.30
Union	6	4.83	0.41
NGO	8	4.50	0.76
University	19	4.26	0.65
Other organization	25	3.92	1.00
Total	154	3.99	1.00

[y] This figure is the mean value of the answer to the question "The precautionary principle should be applied when new materials and new technologies are introduced." (1=Strongly disagree, 5=Strongly agree).

4.3.4 Gender, self-rated knowledge and educational background

Attitudes to regulation vary with other variables besides organizational affiliation. As shown previously there is no statistically significant difference in risk perception between men and women, however there is a difference in their attitude to regulation. There is a statistically significant difference where female respondents have a more positive attitude to further regulation at 4.07 (SD=1.08) compared to men at 3.49 (SD=1.13).[14] Female respondents do not perceive risk lower or benefit higher, but are more in favour to further regulation compared to their male peers (Table 16). There is also a small but statistically significant[15] negative correlation between self-rated knowledge and a positive attitude to further regulation. Higher level of knowledge correlates with a more negative attitude to further regulation of nanomaterials and nanotechnology in general.

Table 16: Attitude to further regulation of nanomaterials and nanotechnology distributed by gender.[z]

Gender	*N*	*Mean*	*Std. Deviation*
Female	46	4.07	1.08
Male	104	3.49	1.13
Total	150	2.33	1.14

[z] The result is significant at a 0,01 level or above in an independent sample t-test.

[14] An independent sample t-test a significant difference at the 0.01 level or higher.
[15] r=-0.177 correlation is significant at the 0.05 level or higher.

To further elaborate on the relation between self-rated knowledge, perceived risk and benefit and the difference between men and women on attitudes to regulation, a segmentation analysis (with z-transformation of values) was conducted. The analysis revealed two distinct groups (see Table 17). The first group consists of 68 respondents that strongly support further regulation, rate high on perceived risk, but rate perceived benefit and self-rated knowledge low. The second group consists of 34 expert stakeholders that are less supportive of regulation, rate perceived risk low, but rate benefit and knowledge high. When compared in respect to gender, males are equally distributed in both groups while females are mainly found in Group 1. Considering the answers to the statements in the questionnaire about qualities of risk pertaining to nanomaterials and nanotechnology (see Appendix C, statements 16 and 18), female expert stakeholders also agreed to a higher extent than men to the statements that risk has disastrous consequences and that the damage might be irreversible (p<.05).

Table 17: Segmentation of expert stakeholders

			Final clusters	
	F	*Sig.*	*Group 1*	*Group 2*
Self-rated knowledge	27.076	0.000	-0.180	0.729
Perceived risk	70.996	0.000	0.575	-0.710
Perceived benefit	62.551	0.000	-0.539	0.716
Attitudes to further reg.	98.531	0.000	0.581	-.0851

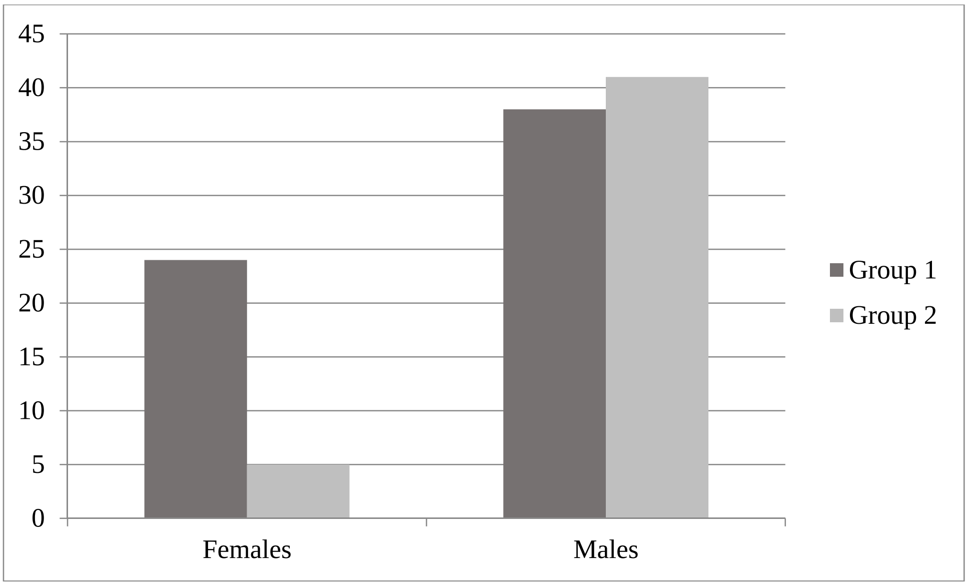

Figure 5:Distribution of group 1 and group 2 by gender.

Experts' support of further regulation is also dependent on disciplinary background. As is shown in Table 18 experts with an education in medicine or law are far more supportive of further regulation compared to the mean, while experts with an education in physics or biology are less supportive.

Table 18: Attitude to further regulation of nanomaterials and nanotechnology[a] distributed by respondent's educational background

Educational background	*N*	*Mean*	*Std. Deviation*
Engineering	43	3,49	1,14
Medicine/pharmacology	5	4,60	0,55
Chemistry	44	3,61	1,17
Physics	17	3,53	1,23
Biology	5	3,40	1,52
Toxicology	10	4,10	1,45
Environmental sciences	4	3,75	0,96
Jurisprudence	2	4,50	0,71
Social science/humanities	14	3,50	1,02
Other	8	4,13	0,64
Total	152	3,66	1,15

[a] The variable for attitude to further regulation is measured with the inverted value of the answer to "The regulation of nanomaterials and nanotechnology today is fully sufficient." (1=strongly agree, 5=strongly disagree).

Summary

To summarize this section on regulation of engineered nanomaterials and nanotechnology, attitude to regulation varies through a number of factors. We can confirm the **Hypothesis K** stating that risk perception is connected to support of further regulation. In contrast to **Hypothesis L** the study suggests that benefit correlates negatively with a positive attitude to further regulation. In accordance with the discussion in the introduction, the plausible reason for this correlation is that experts that perceive high risk want to regulate to prevent harmful pollution. The reason for higher perceived benefit correlating with lower support for regulation is that that low regulation would facilitate development and commercialization. As predicted by **Hypothesis M**, the support for further regulation differs between experts in different stakeholder organizations. In line with **Hypothesis O** NGO expert stakeholders are more supportive of further regulation and expert stakeholders from trade organizations are less supportive. Contrary to this hypothesis, however, there were no differences between industry experts and government experts and **Hypothesis O** must thus be rejected. Possible reasons for this will be discussed in chapter 5 of this report. In this section, we have also identified some other interesting trends in the material outside the scope of the hypotheses. We have seen that attitude to regulation varies with factors such as gender, and self-rated knowledge. Expert stakeholders do not form a homogeneous group with regard to attitudes to regulation and there are different degrees of support for various regulatory measures.

5. Discussion

This study is mainly an explorative study. The aim is to provide an overview of attitudes, beliefs and opinions within the population of expert stakeholders in Sweden who engage in issues concerning nanomaterials and nanotechnology. It contributes with knowledge about which types of organizations take an interest in issues concerning nanomaterials and nanotechnology, and the experts working within these organizations. Nanomaterials and nanotechnology is a topic relevant to many organizations in society. It engages stakeholders in government, industry and civil society in many different ways, such as risk management, risk assessment, promotion, production, regulation and communication. The expert stakeholders who in their work engage with these issues are well educated and have academic degrees from a number of disciplinary fields.

The study has provided information about how expert stakeholders rate risk and benefit for nanotechnology at large, and how they perceived risk and benefit in connection to a number of areas of nanotechnology application. They generally rate benefits with nanomaterials and nanotechnology high and this result is aligned with previous research (Besley et al., 2008). Along with other studies, our study shows that the perceptions of risk and benefit are interdependent so that high perception of risk is linked to low perception of benefit (van Dijk et al., 2015). The relationship can go both ways so that perceived risk might offset perceived benefit, or perceived benefit might reduce risk perception.

Experts rate risk and benefit differently for different areas of nanotechnology application and this result also concurs with previous research (Gupta et al., 2015; Gupta et al., 2012; Siegrist, Cousin, et al., 2007; van Dijk et al., 2015). Other studies show that experts assess nanotechnology applications within medicine to be more beneficial and less risky, the opposite is held for applications within the food sector, understood to have high risk and low benefit (van Dijk et al., 2015). This study looks at a broader range of nanotechnology applications, and we have found substantial differences in how beneficial and risky nanotechnology applications are considered within the different areas of application.

There are several possible explanations for differences in ratings of benefit for the different areas of nanotechnology application. As suggested by previous research perceived benefit might be offset by perceived risk. This study however shows that risk correlates with benefit only for cosmetics and hygiene products, foods and agriculture, and electronics. Other explanations are therefore needed to address how experts evaluate benefits for different areas of nanotechnology application. It is plausible that experts make different ratings for benefit depending on whether they see the field of application as beneficial to society at large, and if they see high potential for innovation to make improvements within the field. In line with suggestions in previous research, low perceived benefit might be explained by other factors such as low urgency and lack of trust in actors within a specific field (cf van Dijk et al., 2015). This however, is speculation in need of further investigation. The study does not provide a full explanation as to why nanotechnology within certain areas of application are seen as more beneficial than others.

There are large differences in how the experts rate risk for different areas of nanotechnology application. Corresponding to ratings of benefit, experts rate risk differently for different areas of application for several reasons. As suggested by the open responses in the questionnaire, risk within a specific area of application is influenced by understanding of toxicity of nanomaterials used in a specific field as well as anticipated exposure. Many experts have a background in natural science, and perceived toxicity and exposure is likely to strongly influence risk perception. As discussed above perceived benefit might influence how the expert rates risk. But as this study shows, there is a correlation between risk and benefit only for applications within *food and agriculture*, *electronics* and *cosmetics and hygiene articles*.

We have compared the different groups of stakeholders, and analyzed how attitude to nanotechnology varies with self-rated knowledge, level of education, gender, disciplinary background, and organizational affiliation. This has shown that perceived risk varies with educational field as indicated by previous research (Powell, 2007). However, this study could not identify any differences along the division between upstream-scientists and downstream-scientists (as suggested by Powell, 2007). Although gender did not significantly influence risk perception, women are less prone to see benefit with nanomaterials and nanotechnology compared to men.

There are also differences in attitude to nanotechnology dependent on expert stakeholders' organizational affiliation. The expert stakeholders generally rate benefits high, and there are only small differences in how the different stakeholders perceive benefit with nanomaterials and different nanotechnology applications. There are however rather large differences in risk perception depending on organizational affiliation. In line with what is suggested by previous studies, trade organizations have relatively low risk perception, and NGO experts high risk perception. Industry experts and government experts, in contrast to previous research, rate risk similarly, and government experts do not rate risk higher than industry experts. There are several possible reasons for why the results diverge from previous research (van Dijk et al., 2015). One possible reason for this is a corporative tradition in the Swedish society, and a sense of shared responsibilities between industry and government.

The study has also provided information on expert stakeholders' attitudes to regulation and to different regulatory measures concerning nanomaterials and nanotechnology. A majority of the expert stakeholders have a positive attitude to further regulation of nanomaterials and nanotechnology, although some consider current regulations to be sufficient. There is general agreement that nanotechnology is a field with substantial challenges for risk assessment and regulation, but this understanding is also questioned by some of the respondents. Expert stakeholders vary in support of various regulatory measure. They generally have a negative attitude to taxation and self-regulation as regulatory measure, but are more positive towards selective prohibition; but there is a significant variance between the different stakeholders. Mandatory labeling as a regulatory measure have a strong support by many of the respondents while many strongly oppose mandatory labeling as a regulatory measure. In other words, there is a notable disagreement about appropriate regulatory measures among the sample of expert stakeholders.

In line with what is suggested by previous research (Corley et al., 2009) high perceived risk correlates with a positive attitude to further regulation. As Corley et al. argues, the underlying logic can possibly be that stakeholders more prone to identify risk with nanomaterials and nanotechnology also want to protect the environment and public health from potential hazards (Corley et al., 2009). In contrast to the study by Corley et al. (2009) this study reveals that high perceived benefit correlates with negative attitude to further regulation. In line with the hypotheses in the study by Corley et al. (2009) this can possibly be explained by the assumption that experts with a more positive attitude to nanotechnology innovation want to see less restriction to facilitate commercialization.

There are differences in views on regulation that depend on organizational affiliation. NGO experts have a stronger support of further regulation compared to the average in the sample of all expert stakeholders. Expert stakeholders from trade organizations are less supportive of further regulation compared to the average. In line with previous research (van Dijk et al., 2015) this can be explained by the different organizations' roles in society. Trade organizations promote industry and commercialization while NGOs strive for public health and environmental protection. Somewhat surprisingly, industry and government stakeholder experts have similar attitudes to further regulation. This can have different explanations. As suggested by respondents in open-ended text responses, industry experts do not necessarily see a conflict between regulation and commercialization of nanotechnology. Two responses from industry experts state that a beneficial climate for investment in innovation is dependent on clear and standardized regulation. A major challenge for nanotechnology regulation is the lack of clear division of obligations and responsibilities, combined with a sense of shared responsibility between principal actors. As van Dijk et al. argues "it has been argued [in the case of nanotechnology] that the traditional separation of responsibilities are fading, leading to new kinds of collaborations characterized by a shared responsibility for decision-making between the state, business and non-governmental organizations" (van Dijk et al., 2015, p. 279).

As discussed in the introduction it has been argued that safe and successful development of nanomaterials requires stakeholder deliberation and a sense of shared responsibilities (Renn & Roco, 2006). The establishment of trustworthy, legitimate and efficient governance frame-works for the regulation of nanomaterials will demand inter-institutional and inter-organizational collaboration from a broad range of societal actors (Bosso, 2016). This will require at least a partial agreement on the problem, and a shared definition of concepts. As this report shows, there are substantial differences and disagreements among the expert stakeholders and there are differences in risk perception, and in attitudes to regulation. But there is also general agreement about several things. There is a common understanding of nanomaterials and nanotechnology as being beneficial to society, and there is also a relatively high degree of support for the idea that nanomaterial and nanotechnology posing substantial challenges to risk assessment and regulation. These commonalities can be seen as indicators of a general agreement of using nano as a framework for addressing issues about risk assessment, management and regulation in a comprehensive way. The large majority of the population of experts from the different stakeholder organizations also agree (at least partially) on the need of further regulation.

6. Conclusion

Nanomaterials and nanotechnology are already in wide use industrially in products in a number of areas. They can be expected to grow considerably in the future due to advances in innovation in a broad array of sectors of application and use. Management of nanomaterials and nanotechnology by institutional and organizational actors will be key for successful commercialization and safety. This study shows that a number of stakeholder organizations within Swedish society are involved in nanotechnology-related activities. The expert stakeholders in general are well educated and have their academic degrees from a broad range of scientific disciplines.

The take-home message of this study is that that multiple factors influence attitude to risk, benefit and regulation of nanotechnology among the expert stakeholders. In line with previous research we can see that the perception of risk and benefit, as well as attitude to further regulation, depend on organizational affiliation. Perception of risk and benefit also depends on the area of nanotechnology application. To understand stakeholders' understanding of risk and benefit with nanotechnology innovation the specific areas of application need to be taken into consideration.

A number of factors influence stakeholders' attitudes to nanomaterials and nanotechnology. Risk perception and perception of benefit steer ideas and attitudes to regulation. Further research is needed for a more in-depth understanding of stakeholders' conceptual models and the heuristics used for evaluating risk and benefit and for positions on regulation. In order to advance knowledge on bottom-up explanations, heuristics and conceptual frames for assessing risk, benefit and stances to regulation, and more qualitative investigations are needed of expert stakeholders' perspectives, through interviews, focus groups and even participant observation.

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Appendix A: Organizations participating in the study

Arbetsmiljöverket
Naturvårdsverket
Trafikverket
Patent och registreringsverket
Kemikalieinspektionen
Statens veterinärmedicinska anstalt
Läkemedelsverket
Inspektionen för strategiska produkter
Statens medicinsk-etiska råd
Myndigheten för samhällsskydd och beredskap
Livsmedelsverket
Skogsstyrelsen
Boverket
Försvarets materielverk
Totalförsvarets forskningsinstitut
Region Skåne
Vinnova
Konsumentverket
Försvarsmakten
Mistra
Swedac
Rymdstyrelsen
Stockholms läns landsting
SwedNanoTech
Svenskt näringsliv
Kemisk-Tekniska Leverntörförbundet
Svensk Handel
Sveriges Byggindustrier
Sveriges textil och modeföretag
Svenskt vatten
Skogsindustrierna
Avfall Sverige
Livsmedelsföretagen
LIF - de forskande läkemedelsföretagen i Sverige
Innovations- och Kemiindustrierna i Sverige
Svensk Solenergi
Teknikföretagen
LRF
WWF
Miljömärkning Sverige
KRAV
Naturskyddsföreningen
Konsumentföreningen Stockholm
LO:s Kemigrupp
Sveriges Ingenjörer
IF Metall
Svenska Byggbranschens Utvecklingsfond
Unionen
Målareförbundet
SIS
Byggnads
Sveriges Kommuner och Landsting
AFA Försäkring forsknings- och utveckling
Tillväxtverket
Business Sweden
Läkare för miljön
Medeon/NanoMedNord
SSF
Swetox
Prevent
IVA Kungliga Ingenjörsvetenskapsakademien
IVL Svenska Miljöinstitutet
Acreo Swedish ICT
Science Village Scandinavia
RISE Research Institutes of Sweden
Innventia
SP Sveriges Tekniska Forskningsinstitut
Göteborgs Universitet
Chalmers
Lunds Universitet
Linköpings Universitet
MyFab
Uppsala Universitet
Renova
AkzoNobel
Tetra Pak Packaging Solutions
Colloidal Resource
Spago Nanomedical
RED GLEAD DISCOVERY
Probation Labs Sweden
Sysav, Sydskånes avfalls aktiebolag
Nordmiljö

Stora Enso
Applied Nano Surfaces Sweden
Insplorion
Spirit Venture
Smart High Tech/ SHT Sinterma
Swerea IVF
Sensair
IKEA
EVP Products
Graphensic
Sandvik
AstraZeneca
Billerud Korsnäs
GKN Aerospace Engine Systems Sweden
Volvo
Smoltek
SCA
Sundströms
Dentsply Implants
BASF
Cementa
Hemocue
LifeAssays
Obducat
Seco Tools
Uponor Innovation
Gammadata Instrument
Bactiguard
Attana
Carmeda
Qunano
Ion Bond
Polymer Factory
Pretium

Appendix B: Statements about regulation of engineered nanomaterials and nanotechnology, rating on a five-point scale

1. *The regulation of nanomaterial and nanotechnology today is fully sufficient.*
2. *Companies will design safe methods for managing nanomaterials and nanotechnologies.*
3. *Companies are more knowledgeable of necessary security measures compared to government authorities.*
4. *Companies should be responsible for formulating regulation in their field of business.*
5. *Voluntary reporting from companies on risks and risk management ensures safe management of nanomaterials and nanotechnologies.*
6. *Mandatory labelling of all products containing nanomaterials and nanoparticles is required.*
7. *Certain nanomaterials and nanoparticles should be banned entirely in products.*
8. *Regulation of nanomaterials and nanotechnology should take citizens' values and opinions into account.*
9. *Regulation of nanomaterials and nanotechnology should mainly be based on scientific risk assessments.*
10. *Detailed management of nanomaterials and nanotechnologies stands in the way for innovations.*
11. *Ethical aspects need to be weighed into the regulation of nanomaterials and nanotechnologies.*
12. *Nanomaterials and nanotechnologies impose special requirements on risk management.*
13. *Excise taxes are an appropriate way of controlling risks with nanomaterials and nanotechnologies.*
14. *Companies have the main responsibility that the substances they manufacture or use do not have harmful health and environmental effects.*
15. *Researchers have the main responsibility to provide knowledge about risks and benefits with nanomaterials and nanotechnologies.*
16. Politicians are more aware of security needs compared to industry.
17. Clearer legislation is required to enable the development of nanomaterials and nanotechnologies.
18. The precautionary principle should be applied when new materials and new technologies are introduced.

Appendix C: Final statements to be rated on a five-point scale

1. More research on risk with nanomaterials and nanotechnology is needed.
2. There are ethical problems associated with the use of nanomaterials and nanotechnologies.
3. Benefit with nanomaterials and nanotechnology weighs heavier than risk
4. Researchers underestimate risk with nanomaterials and nanotechnologies
5. Media provides a true and fair view of the benefits of nanomaterials and nanotechnology.
6. The risk of nanomaterials and nanotechnology weigh heavier than benefit.
7. Media provides a true and fair view of risk with nanomaterials and nanotechnologies.
8. Communication and information create trust in nanomaterials and nanotechnologies.
9. Politicians and authorities underestimate risk with nanomaterials and nanotechnologies.
10. Waste management of nanomaterials and nanotechnologies is associated with risk.
11. Lay people underestimate the risk of nanomaterials and nanotechnology
12. Nanomaterials and nanotechnologies constitute a potential risk for work environment.
13. Union representatives underestimate risk associated with nanomaterials and nanotechnology.
14. The public often has an unfounded fear of new technology and new innovations.
15. Certain risks with nanomaterials and nanotechnologies are difficult to predict.
16. Certain risks with nanomaterials and nanotechnology can have disastrous consequences.
17. Certain risks with nanomaterials and nanotechnology have a low degree of harmful effect over a long period of time.
18. Certain risks with nanomaterials and nanotechnologies can cause irreversible damage.
19. Certain risks with nanomaterials and nanotechnology can take a long time to detect.
20. Certain risks with nanomaterials and nanotechnology may have a sudden course.
21. Potential harmful effects of nanomaterials and nanotechnology are difficult to estimate.
22. More research on risk with nanomaterials and nanotechnology is needed.