UNIVERSITY OF NEWCASTLE UPON TYNE

Increasing knowledge-intensity and complexity;

Nanotechnology and the future of public participation and policy making

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Table of Contents

ABSTRACT 6

ACKNOWLEDGEMENTS 8

LIST OF TABLES 9

LIST OF FIGURES 10

LIST OF ABBREVIATIONS 11

1. INTRODUCTION 12

1.1 Research question and objectives 15
- Research Question 15
- Proposition 15
- Additional objectives 15

1.2 Relevance 16

1.3 Methodology 18

1.4 Outline of chapters 23
- Chapter 2: The context of the research 23
- Chapter 3: Knowledge 25
- Chapter 4: Nanotechnology 27
- Chapter 5: Nanologue 29
- Chapter 6: Analysis 30
- Chapter 7: Conclusion 31

2. THE CONTEXT OF THE RESEARCH 32

2.1 Introducing the socio-economic and technological context 32
- 2.1.1 The changing global arena 33
- 2.1.2 The change of the technological realm 41
- 2.1.3 Economic changes 46

2.2. Changing society **48**

2.2.1 Information Societies 50

2.2.2 Knowledge Societies 54

2.2.3 Summarising societal change 57

2.3 Changing politics **58**

2.4 Summary **62**

3. KNOWLEDGE, EXPERTISE AND POLICY MAKING **63**

3.1 Defining data, information, knowledge and expertise **63**

3.1.1 Data 63

3.1.2 Information 65

3.1.3 Knowledge 68

3.1.4 Practical aspects of knowledge 74

3.1.5 Expertise 77

3.2 Knowledge by acquaintance/description **79**

3.3 Tacit vs. Explicit **84**

3.3.1 Tacit knowledge 84

3.3.1.1 Defining tacit knowledge 84

3.3.1.2 Dimensions of tacit knowledge 87

3.3.1.3 Forms of tacit knowledge 90

3.3.2 Explicit knowledge 93

3.3.3 Transforming tacit to explicit knowledge 93

3.4 Expert knowledge and knowledge gaps **96**

3.4.1 Expert knowledge 96

3.4.2 Knowledge gaps 100

3.5 Information, knowledge and policy making **101**

3.5.1 Policy making 101

3.5.2 Theories of the policy process 103

3.5.3 Policy information and policy knowledge 113

3.6 Knowledge Framework **115**

3.7 Summary **119**

4. NANOTECHNOLOGY 123

4.1 Introduction 124

4.2 What is nanotechnology? 125

4.3 Why is nanotechnology important? 130

4.4 Current developments and trends 134

4.5 Public reactions to and understanding of nanotechnology 137

4.6 The current understanding of the risks of nanotechnology 146

4.7 Nanoscale silver 148

4.8 Summary and outlook 154

5. NANOLOGUE 159

5.1 Introduction 159

5.2 Nanologue's study of nanotechnology 161

5.2.1 Risk perceptions 162

5.2.2 Areas of concern as highlighted by the members of civil society 169

5.2.3 Recommendations and recommended actions 173

5.3 Summary 175

6. ANALYSIS 177

6.1 Introduction 177

6.2 Applying the knowledge framework to different knowledge types 178

6.2.1 Knowledge by acquaintance 178

6.2.2 Tacit knowledge 179

6.2.3 Knowledge by description 181

6.2.4 Explicit knowledge 182

6.2.5 Policy Knowledge and Information 183

6.2.6 Comparing knowledge types 184

6.3 Applying the knowledge framework to policy recommendations 187

6.3.1 Recommended actions and recommendations - Nanologue....188
6.3.1.1 Recommended actions by researchers....188
6.3.1.2 Recommended actions by members of civil society....191
6.3.1.3 Nanologue's recommendations....193
6.3.2 Assessing the recommended actions and recommendations....194
6.3.2.1 Assessing problems....196
Option 1 – Let the expert be the informer....197
Option 2 – Use knowledge elicitation....198
6.3.2.2 Assessing recommendations....200

6.4 Applying the findings to theories of the policy process....209

6.5 Summary....216

7. CONCLUSIONS....221

Nanotechnology....221

Theories of the policy process....225

Outlook....229

BIBLIOGRAPHY....232

Abstract

In recent years, both policy-makers and politicians have been confronted with increasing obstacles towards the interpretation, usage, prediction and application of data, information and of knowledge. This has often resulted in surprises, for instance, as predicted outcomes of introduced policy changes, either did not take effect or simply took on other forms that were not desired. Added to that, new developments and advances in a number of key technological areas have led to the emergence of new knowledge-intensive and technologically-complex disciplines, such as Nanotechnology, Genetic Engineering or Synthetic Biology. The complexity that is inherent in any of these new disciplines poses new challenges to both policy-making and public participation.

This thesis focuses on the question of whether increasing complexity and knowledge-intensity that follow current and future technological developments will lead to a decrease in both the public's interests and ability to participate in the public debate. In addition, this thesis will investigate how policy recommendations are affected when the dependency on expertise, which is due to the inherent knowledge-intensity of these new disciplines, is on the rise. Nanotechnology has been chosen as an example case of one of these new knowledge-intensive and technologically-complex disciplines. By developing and employing a knowledge framework that is based on a practical approach to distinguishing various types of knowledge; public and expert opinions as well as policy recommendations will be analysed in order to determine whether a new approach for involving the public and for the future of policy recommendation is required. Furthermore, by applying this knowledge framework to three selected theories of policy process, special emphasis is placed on the applicability of different types of knowledge and information in policy contexts. An additional aim is to assess the use of terms, such as information and knowledge, in the policy sciences. Using these different types of knowledge, for instance, by making a deliberate distinction between knowledge by acquaintance and knowledge by description, or between tacit knowledge and explicit knowledge, allows identifying what can be known by whom,

and thus will shed new light on both policy recommendations and on what can be expected from the public's involvement in the future.

This thesis will suggest that when dealing with knowledge-intensive and technologically-complex disciplines, the importance of acknowledging different types of knowledge is a prerequisite for improving the quality of policy-making, policy recommendations as well as public engagement. Also, a case will be made against a generic use of the terms knowledge and information in policy literature. As much as policy information does not equal any generic type of information, lacking specificity with regards to information and knowledge in the theories of policy may invalidate or at least challenge some claims made policy scientists, as expected outcomes that apply to one particular type of information may not automatically apply to another.

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List of Tables

TABLE 1: ANCIENT GREEK ORIGINS OF KNOWLEDGE 70

TABLE 2: KNOWLEDGE THAT IS TACIT TO KNOWERS 91

TABLE 3: COMPARING APPROACHES TO THREE EMERGING THEORIES OF THE POLICY PROCESS 108

TABLE 4: SUMMARY OF THE INFORMATION ASPECT OF THEORIES OF THE POLICY PROCESS 109

TABLE 5: KNOWLEDGE FRAMEWORK 117

TABLE 6: OVERVIEW OF UNIT SIZES 128

TABLE 7: A SAMPLE OF APPLICATIONS EXPECTED TO EMERGE FROM ADVANCES IN NANOSCIENCE 128

TABLE 8: TYPICAL SIZES OF VARIOUS BIOLOGICAL SUBSTANCES IN THE NANOMETRE RANGE 129

TABLE 9: NANOTECHNOLOGY FUNDING 132

TABLE 10: DISCHARGES OF SILVER INTO SOUTH SAN FRANCISCO BAY) 152

TABLE 11: TYPICAL SILVER CONCENTRATION OF THE WATER BODIES OF THE WORLD 153

TABLE 12: BENEFITS PRIORITISED 160

TABLE 13: RISKS PRIORITISED 160

TABLE 14: SELECTED AREAS AND THEIR RELEVANCE 164

TABLE 15: GENERAL PERCEPTION OF RESEARCHERS FOR FOUR SELECTED AREAS 167

TABLE 16: GENERAL PERCEPTION OF MEMBERS OF CIVIL SOCIETY FOR FOUR SELECTED AREAS 168

TABLE 17: COMPARING KNOWLEDGE TYPES 185

TABLE 18: BEST CASE SCENARIO OF AVAILABLE KNOWLEDGE OF NANOSILVER 186

TABLE 19: SUMMARY OF NANOLOGUE'S RECOMMENDATIONS AND ACTIONS 195

TABLE 20: TABLOID AND BROADSHEET CIRCULATION IN THE UNITED KINGDOM AND GERMANY 201

TABLE 21: APPLYING THE KNOWLEDGE FRAMEWORK TO SELECTED RECOMMENDATIONS 205

List of Figures

FIGURE 1: WORLDWIDE PATENT FILINGS BY YEAR OF FILING	37
FIGURE 2: TOP 20 PATENT OFFICES BY COUNTRY OF ORIGIN	38
FIGURE 3: EVOLUTION OF WORLDWIDE PATENT FILINGS	43
FIGURE 4: TIMELINE FOR BEGINNING OF INDUSTRIAL PROTOTYPING AND COMMERCIALISATION	130
FIGURE 5: TOP 10 INSTITUTIONS BASED ON EUROPEAN, US AND JAPANESE PATENT OFFICES	137
FIGURE 6: PRIOR KNOWLEDGE OF NANOTECHNOLOGY	139
FIGURE 7: RISKS VS. BENEFITS, NO-INFORMATION CONDITION	139
FIGURE 8: VIEWS OF SUBJECTS ACROSS CONDITIONS	140
FIGURE 9: IMPACT OF INFORMATION ACROSS CONDITION BY PRIOR KNOWLEDGE LEVEL	141
FIGURE 10: PERCEIVED RISKS AND BENEFITS OF NANOTECHNOLOGY	144
FIGURE 11: INFORMATION CHANNELS MENTIONED BY REPRESENTATIVES FROM RESEARCH	165
FIGURE 12: INFORMATION CHANNELS MENTIONED BY REPRESENTATIVES FROM CIVIL SOCIETY	165
FIGURE 13: ELSA PRIORITIES OF INTERVIEWEES	170
FIGURE 14: ELSA OF CIVIL SOCIETY	170
FIGURE 15: WILL ATTENTION INCREASE, DECREASE OR REMAIN THE SAME?	171
FIGURE 16: THE GENERAL PUBLIC'S LEVEL OF ATTENTION	172
FIGURE 17: BROADSHEET COVERAGE OF NANOTECHNOLOGY	203

List of Abbreviations

AIDS	Acute Immune Deficiency Syndrome
APM	Atomically Precise Manufacturing
BMBF	Bundesministerium für Bildung und Forschung (German Ministry for Education and Research)
BPR	Business Process Re-engineering
CRN	Centre for Responsible Nanotechnology
DG	Directorate General
ECE	Eastern and Central Europe
EH & S	Environmental Health and Safety
ELS	Ethical, legal and social
ELSA	Ethical, legal and social aspects
ENP	engineered nanoparticle
EU	European Union
FDA	Food & Drug Administration
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GM	Genetically Modified
GMO	Genetically Modified Organism
GNP	Gross National Product
ICT	Information and Communication Technology
LOC	Lab(oratory) on a chip
IRC	Institutional Rational Choice
N & N	Nanosciences and nanotechnologies
NATO	North Atlantic Treaty Organisation
NDA	non-disclosure agreement
NGO	Non-Governmental Organisation
NT	Nanotechnology
OECD	Organisation for Economic and Cultural Development
PEN	Project on Emerging Nanotechnologies
R & D	Research and Development
RSA	Royal Society for the encouragement of Arts, Manufacturers and Commerce
TQM	Total Quality Management
UK	United Kingdom of Great Britain and Northern Ireland
UNESCO	United Nations Educational, Scientific and Cultural Organization
WAN	World Association of Newspapers
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)
WDP	World Development Report
WTO	World Trade Organisation

1. Introduction

The extent, intensity and the impact of globalisation (Held, McGrew, Goldblatt, & Perraton, 2000) has triggered global economic, social and technological change that will alter established patterns with regard to how people live, how organisations interact with each other and how governments work. The sheer speed with which data, information and knowledge increases will challenge many in both modern (Western) societies and in developing nations alike. Current indicators, such as patent filings (WIPO, 2007) seem to confirm these trends. The new knowledge-based economy, with its increasing number of distinct products, producers and consumers, is said to be far more complex than its industrial predecessor (Stevens, Miller, & Michalski, 2000). The rise of the knowledge worker (Cortada, 1998a), in addition to manual labourers, will add to the already complex layer of knowledge 'haves', and at the same time, increase the gap to the knowledge 'have nots'. New and increasingly complex technological change with its creation and distribution of new technologies has the potential to challenge not only users and consumers, but also governments (Ernst & O'Connor, 1989). These are now confronted with the need to master these new technologies, especially when they are strategically decisive and have the potential to largely shape a country's destiny (Castells, 1996). Biotechnology, genetic engineering, nanotechnology and synthetic biology are examples of these new, and at the same time potentially controversial, technologies.

This thesis addresses the policy challenge that those in government and society more generally face in coping with these technologies and the huge growth in the level of knowledge. According to Kaul (2004) and Tsourikov (2001) the world's knowledge allegedly doubles every six months; overall human knowledge every two to three years, medical knowledge every seven years, and scientific knowledge roughly every decade. Similar statistics exist for information: online information is said to double every six months, unstructured information every three months and corporate information every 18 months; while corporate data doubles every six months and the total sum of printed knowledge and information; that is, everything that has ever been published and retained doubles (Kaul, 2004; Tsourikov, 2001). But it is not only the amount of data, information and knowledge that is increasing. The more important aspect is that data, information and knowledge have become more and more complex and that the types of knowledge required to work with any of these in the future will also increase, and therefore, increase the need to know about information (Krohn, 2001) and knowledge itself.

The increasing importance of information and knowledge has also been acknowledged in the social sciences. Since the mid/late 20th century, knowledge, in itself, has received much attention and its value has since then often been compared to that of traditional, natural resources (Machlup, 1962). Taking tremendous efforts of theorising and philosophising about knowledge as a subject aside, one can still find no single and fully accepted definition that describes the now called 'resource' knowledge. In the areas of business (Nonaka & Takeuchi, 1995) and management sciences (Drucker, 1995), in philosophy (Fuller, 1991), in sociology (Castells, 1996; Stehr, 2002), and in political sciences (Radaelli, 1997; Haas P. M., 2001) the role information and knowledge play has received much attention in recent years. In policy literature in particular, the importance and the perceptions of information and knowledge has also been developed further.

Radaelli (1997) points out that knowledge shapes and moulds actor's preferences and that "*Knowledge – not power – covers the bridge between actors, their interests, and action*" (Radaelli, 1997, p. 166). Sabatier argues that "*policy information is typically used …to buttress one's position or to attack an opponent*" (Sabatier, 1991b, p. 148). However, as this thesis will show, the terms 'information' and 'knowledge' are all too often used very generically, although the terms 'information', and even more so, 'knowledge' are far from generic. Policy literature often uses the term policy information (Straf, 2001) or policy knowledge (Haas P. M., 2001), yet what type of information or knowledge is it? How does it relate to other types of information and knowledge 'out there'? Moreover, terms such as knowledge societies, knowledge workers, knowledge gathering, knowledge representation and even knowledge management have become common. But what is knowledge? Of what is it composed, how is it acquired, how is it nurtured, and how is it best employed for the use of all – if that is desired?

P.M. Haas argues that "[p]*olitical legitimacy rests on a process of knowledge development and diffusion that is scrupulously free of political interference* (Haas P. M., 2004, p. 576). Yet in recent years, both policy-makers and politicians have been confronted with increasing obstacles towards the interpretation, usage, prediction and application of data, of information and of knowledge (Krohn, 2001). This has often resulted in surprises, as predicted outcomes of introduced policy changes either did not take effect at all or simply took on other forms that were not desired and thus required counterbalancing in order to avoid further adverse effects. Notorious examples are public budget predictions, introduced reforms that did not deliver the expected (and, to the public, promised) results or simply 'surprises' that followed the ratification of legislations and treaties.

A number of challenges can be addressed by investigating one particular area of new technology such as nanotechnology. It will be argued that increasing complexity and knowledge-intensity will lead to an increased dependence on experts as a means to accessing as well as interpreting specialist knowledge. From a policy perspective, one needs to ask what impact this new complexity has. Similarly, how is this new complexity going to impact public participation? Science and technology are complex human activities (Ziman, 1984) that change rapidly in form and content. Yet, every so often, science and technology can also be harmful. Here, the difficulty is for the policy-maker to obtain a level of understanding that goes beyond the mere usage of this technology in order to assess both risks and benefits. What is required instead is an active transfer of expertise - from the technology provider, patent holder, or any other directly involved party that has the required expertise - to the actors and bodies involved in policy-making. As this appears improbable, an alternative means of accessing and/or involving the required subject matter expertise in the policy cycle is required. This could include knowledge elicitation or using experts directly. Furthermore, the dependence on experts to be used as 'translators' of knowledge-intensive subject matters for either the public or government asks questions as to how non-experts ought to deal with subject matters that are too complex to be understood by a mere layperson? What if, going forward, only experts will be knowledgeable enough to comprehend certain subject matters? How will they be involved in a policy-making process, especially when these experts are employed by major corporations that quite frankly want to protect their assets, such as patents? And, again, how will the public be affected and what happens if the public has no interest in any of these new complex technologies, for instance, due to a lack of understanding?

1.1 Research question and objectives

Research Question

Will increasing complexity and knowledge-intensity that follow current technological developments and advances challenge policy-making and also hinder the public's ability to participate in the public debate?

Proposition

The main argument of this thesis is:

Due to the increasing knowledge-intensity and complexity of new and emerging technologies, a distinction between various types of information and knowledge is beneficial, if not required, in order to benefit both the public discourse and policy-making. Furthermore, by distinguishing between various types of information and knowledge, theories of the policy process can be assessed towards their applicability to complex, knowledge-intensive and expertise dependent subject matters, such as nanotechnology.

Additional objectives

There are a number of additional objectives that are central to this thesis:

- To establish a framework that focuses on different knowledge types that can be used to make distinctions vital in practical contexts.
- To assess selected criteria of a number of theories of the policy process with regards to the usefulness of identifying different types of knowledge and information. The three selected theories are Ostrom's Institutional Rational

Choice framework (1991), Moe's Structural Choice approach (1995) and Sabatier's Advocacy Collation framework (1988).

- To investigate one knowledge-intensive area in detail that is relevant for policy-makers and the public.
- To identify tools that could help overcome potential stumbling blocks for policy-makers and the public.

1.2 Relevance

The selected topic is relevant to the political sciences because of two main factors: Firstly, it will be shown that even though information and knowledge have received increased attention, in some areas, it has not gone far enough. Secondly, it will show that the rise of new and increasingly converging sets of technology poses challenges to both policy-making and public participation.

Meehan defines a policy as follows: "*A policy provides a solution to a choice problem; the problem is always analytically prior to the policy* (Meehan, 1993, p. 58). By this, Meehan means that a problem, for instance climate change, is always known before actions (a solution) can be taken. However, what if this is no longer true? What if a policy is required, although not much is known about the problem? What if there is a need or a desire to put regulation in place because 'negative impacts' of a new technology, for instance, are expected, feared or assumed? By now, there are numerous fields, such as nanotechnology or genetic engineering, that have become rather difficult for the non-expert to comprehend, and yet politicians, bureaucrats and policy-makers need to set the direction forward and, at the same time, ensure the public that governments can be trusted to deal with knowledge-intensive subject matters (Frankfort-Nachmias & Nachmias, 2002). Climate change, to use that example again, has been pursued for many years by experts only and at the same time failed to gain larger public recognition. The latter part is now slowly changing, partly due to media coverage in the wake of Hurricane Katrina that severely affected the United States, and partly due to the fact that a number of prominent public figures have 'adopted' the topic (for instance, Al Gore).

Nevertheless, gaining public recognition and comprehending a topic as complex as climate change are two different things. Worldwide there are only a small number of experts researching climate change who can truly claim to more or less fully comprehend the topic as a whole. What does this mean for the public? Should they simply give up caring about it because they cannot understand it? The inclusion of the public in political and social debate is seen, amongst other things, as a sign of political stability (O'Flynn, 2007). Furthermore, it is also seen as a sign of political equality, "*if it means the inclusion in a decision-making process on equal terms of all who are subject to its decisions*" (O'Flynn, 2007, p. 738). What, however, if this increasingly becomes an issue, as the public can neither comprehend the content nor the reasoning behind decisions due to a lack of understanding or inability to access the relevant information and required knowledge?

For the past two thousand years, every major government in the world has supported centres of knowledge such as libraries, universities, monasteries, and departmental libraries and archives (Cortada, 1998a). In recent years, however, much of the knowledge-intensive information is being held by corporations, research institutes, in patents, or in other inaccessible forms of both storage and ownership. "*For a thousand years, … guilds certified the ability of craftsmen making everything from jewelry to armor*" (Cortada, 1998a, p. 9). But now, who certifies the skills and ability of policy-makers, let alone politicians? Although the technological change led to an enormous increase in the quantity of information that is now available, it did not automatically increase in the value of information (Keohane & Nye, 1998). On the contrary, finding the right information for the right purpose has become more difficult.

Why is the topic important? Nanotechnology, and its potential impacts, is only one example of a knowledge-intensive and expertise-dependent technology. However, nanotechnology, as used in the context of this thesis, could easily be substituted by a different, and perhaps even more complex technology, for instance, Synthetic Biology. What is being suggested here, as part of this research, is that new ways of dealing with matters of enormous complexity are required so that society is not challenged *per se*. The main point is not to draw a 'doom and gloom' picture about anything that bears risk. Due to the enormous technological advancements of the last few centuries, it is only natural that new, and especially converging, sets of technologies bear proportionally greater risks than advancements of previous centuries. Methods and tools that have been used in the past to deal with vast changes may not apply as before. This is where the need to fully understand data, information and knowledge comes into play. Only if politicians and policy makers have a sound knowledge and understanding of the skills that are required to deal with complex information can the public be both prepared and feel informed about complex subject matters.

1.3 Methodology

In order to answer the research question and to investigate the additional objectives, an approach had to be chosen allowing for the required breadth of the research to be taken into account. The research topic sits within political sciences, and to a certain extent within policy sciences, but as it is of such a broad spectrum that a multi-disciplinary approach was required. Thus, areas such as contemporary discussion in disciplines such as Politics in general, Policy Science/Studies, Management Studies/ Sciences, Information and Communication Sciences and, of course, Nanotechnology had to be taken into account.

The research focuses on a case study and is a detailed illustration of a broader phenomenon (Hague, Harrop, & Breslin, 1998). Yin defines a case study as an "*enquiry that investigates a contemporary phenomenon within its real-life context*" (Yin, 1994, p. 13). In the context of this thesis, this can be interpreted as follows: the contemporary phenomenon is the rise of knowledge-intensive and increasingly complex technologies and the real life context is the impact this has on areas such as public participation or policy making. Furthermore, it aims to broaden the understanding of currently held views, and where possible, propose options. A particular example is the use of information in policy-making. There seems to be common agreement amongst researchers that information and knowledge play an important, if not even crucial role (Sabatier, 1988, 1991; Haas P. M., 2004; Radaelli, 1997). Yet, when it comes to the use of the term information in policy literature, one often finds this usage to be generic, if not unspecific. Similarly, it is all too common these days to make policy recommendations. Yet, how useful are such policy recommendations in a real-world context, when they need to hold up against scrutiny? In order to find this out, and to fully take the complexities of this research into account, a multi-disciplinary approach that has been chosen. This was supported by a literature review encompassing the following areas:

- Globalisation/global transformation
- Data, information and knowledge
- Information/ Knowledge society
- Policy studies and policy-making
- Public perception and communication of nanotechnologies
- Nanotechnology and risks of nanotechnology

An overview of the multi-disciplinary literature used in this thesis is provided in chapter 1.4.

It is expected that nanotechnology is only the first of a new breed of emerging technologies, which potentially will have far-ranging consequences for a variety of areas, such as society, economy, and politics. Currently, nanotechnology is neither a standard nor a representative type of technology, mostly due to its nature of being 'a set of converging technologies' rather than a single technology. However, it is expected to become a typical technology in the future. Thus, nanotechnology, as used in this thesis, is a prototypical case. It is prototypical because of the inherent complexity and knowledge-intensity, and as such poses a very difficult information and knowledge challenge to policy-making and to political participation.

Before selecting an example of an emerging complex and knowledge-intensive technology that could be used in a prototypical fashion, the following choices were reviewed: genetic engineering, nanotechnology, and synthetic biology. For the purposes of this research, it was important that the selected choice met a number of criteria: available data and research literature, already available practical applications and products (ideally unbeknownst to the public), first signs of an existing academic and/or public debate, an available timeline for further product launches and the potential to pose difficulties for future policy-making. Synthetic biology did not meet these criteria due to the lack of available products, a sufficiently large enough body of knowledge and available data and an acceptable timeline for product launches. Genetic engineering also did not meet a number of criteria, when excluding GMO, a subject that has been sufficiently discussed in recent years. Thus, the decision was made to select nanotechnology as it provided just the right amount of acceptable criteria. Nanotechnology, although still only emerging can already show a number of products on the market, has started a discussion in both public and academia, including the social sciences, and there are clear indications of what products/uses to expect next. These factors were important in the selection of nanotechnology, as the "*danger with the prototypical case is that it involves a bet on the future"* (Hague, Harrop, & Breslin, 1998, p. 277). Thus, it was necessary to ensure that nanotechnology did not turn "*into a dud*" (Hague, Harrop, & Breslin, 1998, p. 277) during the execution of the research.

In order to investigate whether nanotechnology has indeed the characteristics of being a forerunner in trends, a characteristic that applies to prototypical cases, international funding (ESRC, 2007; Nanotechwire, 2008) and investment activities (Lux Research, 2007) over the past decade have been studied. This, then, led to the study of recent research activities (Bainbridge & Rocco, 2005; Babu, Deepa, Shankar, & Rai, 2008) as well as forecasts of nano-technological development (PEN, 2007; Nanowerk, 2007). Once it had been established that nanotechnology fits these characteristics, the main work for the knowledge framework could be undertaken.

This included the research of concepts such as knowledge by acquaintance and description, tacit and explicit knowledge as well as policy knowledge, as they needed to be established in order to form the core of the knowledge framework. The idea behind the knowledge framework was to design an analytical tool that enabled not only the cross-comparison of various forms and concepts of knowledge, but also allows for the application of findings in the areas of public perception of nanotechnology, the risks from nanotechnology and to policy recommendations. For such a comparison to be successful, it was important to design the framework in a way that allowed the comparison of the varying key components and key characteristics of the different knowledge types against a set of variables, such as the scope of each knowledge type or the characteristics of the knowledge holder.

Additionally, the core of the knowledge framework can be applied against select parameters of theories of the policy process and policy information. Here, the aim was to critically assess three selected theories with regards to the findings of the knowledge framework.

In order to analyse the impacts of nanotechnology on both policy-making and public participation, sufficient data for analysis had to be gathered. However, due to the novelty and the complexity of nanotechnology research, it has been decided to use the raw data Nanologue (2005, 2006) provided, instead of personally obtaining primary research data. Initially, the idea was to obtain such data by means of questionnaires and interviews. However, it soon became clear that the quantity and quality of data that could have been obtained this way would not hold up to the extensive scope of Nanologue's research, which not only received substantial funding from the EU's 6th Framework Programme but which also involved four research institutes across three countries. Data collection on a scale presented by the Nanologue group would have been beyond the scope of this thesis, hence the decision to use Nanologue research instead. This meant, however, also having to accept limitations. The most important one comes with the data Nanologue provided; in particular, Nanologue's selection of the members of civil society. Here, it had to be accepted that although Nanologue chose to select members of civil society that had had at least some prior dealing with nanotechnology; using random members of the public would have been more useful.

The analysis was undertaken by applying key findings established in chapters 4 to 5 to the knowledge framework. This has been done firstly, by applying the five knowledge types of the knowledge framework – knowledge by acquaintance, knowledge by description, tacit knowledge, explicit knowledge and policy knowledge – to nanotechnology and to the selected case of nanoscale silver. This was done in order to establish a baseline of 'what can be known by whom' in the context of nanotechnology and nanoscale silver, as this has implications for both public participation, the public's knowledge of nanotechnology and nanotechnology-related policy-making. Based on this, policy recommendations and generally recommended actions were assessed in the same manner. Similarly, three selected theories of the policy process were examined against the knowledge framework. Both of these exercises aimed at establishing as to whether the intentional distinction between different knowledge types, as proposed in this thesis, would potentially benefit public participation and policy making. The answer to this is provided in the conclusion.

As mentioned at the beginning of this chapter, a multi-disciplinary approach was chosen in order to research the topic. Thus, a brief overview of the literatures used will be given below.

The globalisation and transformation literature reviewed for this thesis sits mainly within political sciences (Held, McGrew, Goldblatt, & Perraton, 2000) and economic geography (Amin & Thrift, 1999), when taking a spatial component into account. However, other authors, such as Beck (2000) and Castells (1997, 1998, 1999) have a background in sociology. When positioning the research, a certain historical perspective was required. Here, perspectives on the historicity of change, and particularly of technological and economic changed are provided by Landes (1999a, 1999b) and Mokyr (1992). Literature about data, information and knowledge has been sourced from various backgrounds. For instance, Lyre (2002) approaches data and information from an Information Sciences perspective, whereas MacDonald (1999, Davenport and Prusak (2000) and Drucker (1995) approach it from a Business Studies/Management Sciences perspective. A similar approach was required when discussing knowledge. A review of literature from disciplines such as philososphy (Russel, 2001), and particularly epistemology (Sosa & Kim, 2001; Williams, 2001), was combined with Business Studies/Management Sciences (Cortada, 1998a; Nonaka & Takeuchi, 1995) literature and sociology (Stehr, 2002).

For the policy section, and in particular, for the sections on theories of the policy process and on policy information, a broad spectrum of politics literature has the reviewed, ranging from governance (Peters & Pierre, 1998; Pierre, 2000), policy and knowledge studies (Radaelli, 1997), organisations and institutions (Lustick, 1980;

Peters & Pierre, 1998), general policy literature (Peters & Pierre, 2006), literature specific to policy information (Straf, 2001; Haas P. M.,1991, 2004) and theories of the policy process (Ostrom, 1991, 1994; Moe, 1995; Sabatier 1988, 1991).

The nanotechnology literature can roughly be divided into three groups: pure science based literature (Babu *et al.*, 2008; Guo *et al.*, 2006), scientific (Ehdaie, 2007; Maynard, 2006) and popular scientific (Behra & Krug, 2008; Drexler, 1986; Gatti & Montanari, 2008) accounts reporting about both progress and risks of nanoetchnology, and official and public communications from governments (BMBF, 2006), governmental bodies (Commission, 2004, 2005) and other organisations (Royal Society, 2004; ESRC, 2003). In addition, up-to-date data on funding, products and other recent developments in the field has been obtained from various Internet resources (Nanowerk, 2007; Nanotechwire, 2008; PEN, 2007, 2008). Science communication literature formed the main body of the review of the current public debate (Scheufele *et al.,* 2007) and studies into public acceptance of nanotechnoloy (Currall *et al.*, 2006; Kahan *et al.*, 2007, 2008).

1.4 Outline of chapters

Chapter 2: The context of the research

This chapter aims to position the research, thus focusing on central questions such as: Where does the topic fit? Why is the topic important? What are the main challenges? By and large, this chapter is a general introduction to the topic and provides the starting point and basis for chapters 3 and 4. Drawing on Held *et al.* (2000), this chapter discusses recent changes that have happened on a global scale. Without further engaging in the recent globalisation debate (Beck, 2000; Varwick, 1998; Bhagwati, 2004), the main emphasis is to find out what role Information and Communications Technologies (ICTs) played, and what this means with regards to knowledge and increasing knowledge intensity?[1] This, then, draws attention to the role of corporations in today's globalised world, especially with regards to holding patents (WIPO, 2007).

[1] The term knowledge intensity can have two different meanings. In the context of this thesis, it is used to illustrate the extent to which industries produce extremely complex high-technology products.

Following the above discussion, emphasis is being put on technology and technological change. After providing definitions on what constitutes technology (Walker, 1999; Ernst & O'Connor, 1989), and what technological change means, the importance of technological change in historical context will be discussed. For instance, Castells (1996) explains the most recent technological change as a result of the rise of ICTs. According to Castells, this will lead to the establishment of the Network Society (Castells, 1996). Castells (1996) also describes information technologies as a converging set of technologies; it will be shown that these new information technologies now include new disciplines, such as biotechnology and nanotechnology. These new and converging ICTs are, due to their nature, also being referred to as complex and knowledge-intensive technologies.

The importance of information and/or knowledge as a new resource in the economy was first examined by Fritz Machlup (1962). Since then, numerous authors have drawn on Machlup’s original work; for instance, Castells (1996, 1998) and (Webster, 2001). This new knowledge-based economy is not only more complex than its predecessor the industrial-based economy, argue Stevens *et al.* (2000), but also offers new chances for economic development, as knowledge can be transferred more easily and cheaper than (some) raw materials, according to the World Bank (1999).

What knowledge and the new knowledge-based economy means for society is discussed next. Societal change based on the new importance of knowledge may have far-reaching consequences, but also offers opportunities. However, it appears that there is no agreement about where this will lead. Two concepts, therefore, need further explanation; that of the information society and the knowledge society. For Webster (2001), the defining characteristic that best describes the new information society is ‘information’ and the new computational power. Krohn (2001) argues that the defining characteristic is the influence of computer-based networks and the globalisation of ICTs. This is different to the concept of a knowledge society that is based on dealing with complexity, uncertainty, insecurity and ambiguity (Krohn, 2001). Another feature of the knowledge society is the dominance of knowledge work (Cortada, 1998a), or rather, the increasing number of professions that work with knowledge, as opposed to manual labour (Stehr, 2002). When summarising societal change, special emphasis is paid to the dependency of expert knowledge, leading to new politics of knowledge (Cozzens and Woodhouse 1994).

Keohane & Nye (1998) argue that ICTs will determine power in the 21st century. New challenges, such as intense growth rates of information and knowledge and the development of global networks for information and communication, will alter historically grown patterns of power, thus affecting not only states, but also organisations and ordinary people. In addition, increasing complexity and knowledge-intensity will also challenge established societal processes, such as public participation and governance.

Chapter 3: Knowledge

By looking at practical examples of knowledge, i.e. knowledge by description, knowledge by acquaintance, and tacit knowledge, this chapter intends to find out the extent to which exactly these approaches can be utilised as alternative access routes to expert knowledge and, as such, could be seen as a means to be implemented as practical helpers to support both public engagement and decision-makers involved in policy change. The chapter also explores the extent to which an understanding of the practicalities of various concepts of knowledge may help to understand an active knowledge transfer process, or, at least, viable communication processes that enable the public to actively participate in establishing sufficient understanding required to engage in an open debate or in policy-making efforts.

This chapter begins with an investigation into the several components that constitute the main body of interest - knowledge. A number of definitions are required to establish the scope of this study, in particular that of data, information, knowledge, and expertise. After defining data, a more detailed introduction of the term 'information' is required, as it forms part of common terminology such as, information age, information society, information economy or information technologies. Rowley concludes that the term 'information' is an ill-defined concept and must therefore always be used context-specific (Rowley, 1998). Lyre (2002) approaches information differently, by employing information theory, Lyre argues that information is only what is understood and what generates more information. How this plays out in relation to nanotechnology is shown in Chapter 5 (Analysis). Other approaches to information are based on business studies or management science (Davenport & Prusak, 2000), and on power politics (Keohane & Nye, 1998).

Knowledge cannot be explained as clearly as data or information can. Cortada put it fittingly: "*the literature on the history of information and knowledge would fill a building*" (Cortada 1998a, 5). Therefore, a discussion of the ancient Greek roots of knowledge and their various meanings provides an overview and also an entry point into the subject matter. Davenport & Prusak (2000) provide a working definition of knowledge that is seen as being useful and applicable to this thesis. Furthermore, authoritarian modes of knowledge and a number of relevant philosophical aspects of knowledge are introduced as well. For Lundvall and Johnson (1994), practical aspects of knowledge can be classified as know-what, know-why, know-how, and know-who, which is somewhat similar to Aristotle's concept of *episteme, techné* and *phronesis*. Following this discussion of practical knowledge examples, a review of expertise completes this section of definitions and introductions.

Although generally attributed to Bertrand Russell (2001), knowledge by acquaintance was first introduced by Grote in the 19th century. Differentiating knowledge by its form of acquisition, a central point of this thesis has, surprisingly, not been tackled in the literature since Russell. It offers several advantages with regards to today's complex and knowledge-intensive technologies. Practical examples, be they general or technology specific, can be used to illustrate different aspects of direct (knowledge by acquaintance) and indirect knowledge (knowledge by description). A different approach to distinguishing between direct and indirect knowledge was taken by Michael Polanyi (1966, 1969, 2000). By investigating uncommunicated and/or uncommunicable knowledge that people have, M. Polanyi described tacit knowledge. The concept was quickly taken up by others, most notably in the late 1990s/early 2000s when tacit knowledge was a key component to Knowledge Management. This was largely due to Nonaka and Takeuchi (1995) when they published 'The Knowledge-Creating Company'. Gourlay (2002, 2004) carried out extensive reseach on tacit knowledge, its roots and dimensions, and discovered that there are various forms, some pertaining to individuals and some to groups. Subsequently, a question that is often being asked with regards to tacit knowledge is whether it can be transformed into explicit knwoledge. Here, a number of authors disagree (Tiessen, Andriessen, & Deprez, 2000), while others maintain it can be done under certain circumstances (Collins, in Gourlay 2002).

Society's increasing need for experts, be it as expert witnesses in court cases (Page & Lopatka, 2004) or on TV (Boynton, 2007) is subject to a discussion with the aim of emphasising on this new dependency. Geißel & Penrose (2003) argue that society itself has changed over the last few decades, resulting in a dilemma. On the one hand, there is the general fear that results of scientific expertise have been influenced by economic or political factors. On the other hand, there is the insecurity of the public about its ability to understand and correctly interpret scientific result. Both issues have far-reaching consequences when applied to knowledge-intensive new technologies (Currall, King, Lane, Madera, & Turner, 2006).

Finally, the role of information and knowledge in policy-making is explored. After a brief introduction to policy-making in general, three different approaches to theories of the policy process are introduced. These have been chosen because of their relevance on the research topic. By using Ostrom's (1991) Institutional Rational Choice (IRC) approach, Moe's (1995) Structural Choice approach and Sabatier's (1991) 'Advocacy Coalitions Framework' the role of information will be investigated, especially when actors face uncertainty.

Chapter 4: Nanotechnology

Nanotechnology has been chosen to illustrate the complexities that come with it as a relatively new area within science and as a new technology that has the potential to re-shape the modern industry of the 21st century. The dependence on experts and the inherent knowledge-intensity is something that nanotechnology shares with a number of other emerging technologies that exist. Some of them, such as synthetic biology, have the potential to become even more complex than nanotechnology. This exactly is the point that needs to be understood when discussing knowledge intensity; the examples shown throughout this thesis are merely examples of an already known discipline, and of areas that are already well-known and discussed within, at least, the scientific community, and to a certain, although, limited extent, the public. Nanotechnology, like genetics and biotechnology before it, will not be the last and final complex technology. Rather the opposite may hold true, it is very likely that it is one of the first truly complex technologies that has the potential to re-shape everything that is known and taken for granted.

The chapter starts by introducing a number of different definitions of what nanotechnology is, and in the course of doing so, highlights some of its complexities. One of the current debates focuses on the direction in which nanotechnology might go. On the one hand, there is K. Eric Drexler who insists that the current focus should be on atomically precise manufacturing (APM), while having the long-term goal of creating self-replicating nanostructures (Drexler, 1986). The Centre for Responsible Nanotechnology rebuffs Drexler's approach and vision, and offers instead a definition of what nanotechnology is, and an explanation of what it is not (CRN). Following a discussion and illustration of current funding initiatives, current trends and a realistic timeline of nanotechnology development are introduced. These current trends offer insights into already available products, often unknown to consumers (Nanowerk, 2007), which in turn asks questions about the public perception of nanotechnology.

A number of studies into the public perception have been carried out (Kahan *et al.*, 2007, 2008; Currall *et al.,* 2006; Nanologue 2006). Somewhat unsurprisingly, there is a common consensus that the public does not know much about nanotechnology, the same applies to public perceptions of risks of nanotechnology. Kahan *et al.* (2007, 2008) make the point that when risks are being discussed, risks perceptions follow along the lines of cultural predisposition; that is, being shaped by already existing values. Risk-based research focussing on nanotechnology is still relatively scarce, and the majority of studies have been carried out while focussing on human health, thus somewhat neglecting environmental risks (Behra & Krug, 2008). This can be attributed to the novelty of nanotechnology itself and to the lack of detection capabilities of nanosized particles, as Maynard (2006) points out. In order to illustrate the current dilemma of nanotechnology risk assessment, nanosilver (or nanosized silver particles) will be investigated in order to shed some light on nanotechnology risks. Nanoscale silver is currently one of the most popular, albeit already highly criticised, materials used in already available products, such as toothpaste, washing machines, and wound dressings. This is because nanoscale silver is said to have antibacterial and antifungal properties (FDA, 2006), yet at the same time, it is already known that it has the potential to damage aquatic life (Behra & Krug, 2008). This investigation of the current understanding of nanosilver is also critical to the comparison of different knowledge types in the analysis part of this thesis (Chapter 6).

Chapter 5: Nanologue

Chapter 5 provides the relevant data required for the analysis in chapter 6. The general background to Nanologue's research, and a familiarisation with Nanologue's research design is provided, and the results of Nanologue's assessment of the knowledge and awareness of nanotechnology among the participants of their studies, the researchers and other members of civil society, is discussed. Nanologue chose seven particular aspects for the research, of which four have been selected as main areas of interest for this thesis: environmental performance, human health, access and acceptance. In addition, Nanologue's findings on the varying uses of information channels by both researchers and members of civil society are discussed, as these not only impact the areas of available knowledge and information, but also provide insight and a means for cross-comparison as to how the public informs itself.

The main aim of this chapter is to establish areas that can be assessed against the knowledge framework. Thus, after reviewing the initial findings, an exercise is undertaken which focuses on general and policy recommnedations, and on recommended actions. In addition, the distinction between nanotechnology and the environmental, legal and social aspects of nanotechnology is being discussed. This is a necessary step which impacts on the recommendations given by both the participants of the study and by Nanologue's itself. Throughout the chapter, and where possible, Nanologue's data and results were cross-referenced against other research, for instance that of Kahan *et al.* (2007, 2008) and Currall *et al.* (2006).

Chapter 6: Analysis

Following the discussions on knowledge (Chapter 3), nanotechnology (Chapter 4), and the case study of Nanologue (Chapter 5) this chapter aims to apply findings of these chapters in order to identify potential risks with regards to knowledge-intensive and expertise dependent technologies and society. In order to do so, this chapter introduces a framework that details the types of knowledge discussed in Chapter 3 in the context of nanotechnology with the aim of establishing an analytical framework. For instance, knowledge by acquaintance in a nanotechnology context refers to knowledge that has been directly acquired by a researcher working on nanotechnology research. Practical examples, such as Oberdörster *et al.* (2002), who investigated the impacts of the exposure of water fleas (*Daphnia magna*) to nano-iron particles, are used to explain what this means in the context of this thesis. In the same vein, an example is provided for explaining tacit knowledge in a practical context (Babu, Deepa, Shankar, & Rai, 2008) in order to explain its practical implications.

As part of this analysis, two other options for dealing with some of the main issues identified by Nanologue (2006) and other researchers (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008) are introduced. A common recommendation with regards to public engagement is 'simplification of content' (Nanologue, 2006); that is, making nanotechnology related research findings understandable to the public. Yet, the majority of current research fails to detail exactly how this can be achieved. Thus, two options will be introduced, with both their advantages and disadvantages. Option 1 suggest that the researchers should also be the informers, whereas Option 2 suggest that knowledge elicitation can be used to obtain expert knowledge and, then, to convert it into descriptive knowledge (or explicit information). Another recommendation of Nanologue (2006), the correct use of mass media, is assessed by looking into how the public informs itself. Research by Petersen (2006), as well as observations made for the purpose of this thesis confirm that nanotechnology is simply not in the news enough for the public to form an objective opinion, thus corroborating research carried out by (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008).

The final part of the analysis is the comparison of three different theories of the policy process against the knowledge framework. In particular, the aim of the knowledge framework in this context is to use the different knowledge types in an attempt to identify which, if at all, could be used to explain the terms information, knowledge and expertise used by the aforementioned theorists.

Chapter 7: Conclusion

Chapter 7 summarises the main findings of this thesis and answers the research question whether increasing complexity and knowledge-intensity will challenge policy-making and also hinder the public's ability to participate in the public debate? It will highlight what the findings of this thesis indicate with regards to the different knowledge types, policy-making and public participation and also assess the additional objectives, as specified in Chapter 1.2. The conclusion will also attempt to place the findings of this thesis in the context of future nanotechnology research with regards to policy-making and public participation.

2. The context of the research

The main aim of this chapter is to position the research with regard to societal, political, technological, and economic changes and developments that have occurred recently, to show where the topic fits, and why the research is important. The intention is to identify what has happened in the past few decades, to explain these changes and to establish a number of challenges that are used and analysed in later chapters in more detail. After discussing the socio-economic and technological context, including the changing global world, the technological and the economic context, this chapter explores the impacts on society. Common terminology used in current discussions, such as the knowledge society, are explored further with the aim of establishing whether societal changes have indeed been ground-breaking and, if that assumption is correct, to establish what this may mean, going forward. This chapter will draw on a number of different disciplines, such as business and management studies, geography, sociology and politics in order to set the context.

2.1 Introducing the socio-economic and technological context

In the introduction to the 'Resources for the knowledge-based economy' series, Laurence Prusak (1998) asks why there is such an increased interest in knowledge, and why now:

> Why the focus on a subject that, at some levels, has been around since the pre-Socratic philosophers? It is yet another one of the multitudinous management enthusiasms that seem to come and go like random natural phenomena? We don't think so! (Prusak, 1998, p. vii).

Four broad trends play a sufficient role for Prusak to believe that the current interest is not just mere 'hype'. First of all, Prusak identifies globalisation as a major trend that puts a variety of organisations, be they economic, political or social, as well as entire societies, under enormous pressure. The result is an increasing interconnectedness of the world (Landman, 2000), which does not come without a number of issues ranging from disparities in the distribution of wealth to rising inequalities with regards to access to education and knowledge. Secondly, there is a rise in the awareness and acknowledgement of specialised knowledge that helps organisations in "*coping with* *the pressures of globalisation*" (Prusak, 1998, p. viii). These pressures, such as increased global competition, led also to a changed attitude towards science and technology, as product life-cycles became shorter and the need to bring new innovations more quickly to markets increased. A third point is a rise in awareness of knowledge itself being a factor of production. Although this has been known since the 1960s (Machlup, 1962), it was only acknowledged by many organisations since the late 1980s that knowledge creation (Nonaka & Takeuchi, 1995) itself can help sustaining a competitive advantage. The final point for Prusak is the availability of cheap ICT-based networking that allows participants to work with, and to learn from, one another. The resulting changes, especially the impact on society are discussed in the following sections in more detail.

2.1.1 The changing global arena

So far the 21st century has been associated with the so-called information age (Alberts & Papp, 1997) and various attempts to find the right terminology indicate that there is a common perception that modern societies indeed have arrived at a stage where information plays increasingly a key role. Nonetheless, the vagueness of terms used to describe the latter have not helped much to determine whether or not current societies now moved towards becoming an information society (Webster, 2001), a network society (Castells, 1996), a knowledge society (Stehr, 2002), something in between or something completely different. Early attempts to describe the upcoming changes have mainly been driven and influenced by the advancement of computers and the accompanied effect of ever decreasing costs of computational transactions and thus the 'computer age' was a common term. Soon, however, it became clear that computers themselves are not solely responsible for this transformation. Today, there is not much doubt that globalisation has fostered this development, be it in a way where globalisation functions as a driver of this development or where globalisation is merely a result.

One must acknowledge that globalisation has changed the way in which this world functions, which is not to say that globalisation is either a desired or possible end-state (Landman, 2000). Yet, globalisation had and still has knock-on effects on various areas that are in the process of being changed. For instance, technological advancement functions as a key enabler within the globalisation/ transformation process and therefore plays a major role. As a result, the economic realm has changed immensely within the past two decades and thus also changed modern societies (Castells, 1996).

Globalisation has become one of the most fashionable terms over the last decade, but defining what exactly globalisation means is an entirely different story (Beck, 2000). Held *et al.* view globalisation as "*a process (or set of processes) which embodies a transformation in the spatial organization of social relations and transactions – assessed in terms of their extensity, intensity, velocity and impact – generating transcontinental or interregional flows and networks of activity, interaction, and the exercise of power*" (Held, McGrew, Goldblatt, & Perraton, 2000, p. 55). Practically, this describes the new flow and movement of people, goods and information as well as their interactions and impact on each other. What has changed is a substantial decrease in the time and effort required in order to access both goods and information and share it across borders. Varwick, in contrast, describes globalisation as a process of increasing relations between societies and problem areas with the effect that actions in one part of the world reach (and influence) societies and problem areas in another part of the world (Varwick, 1998). This also includes the erosion of a state's territory, nationality and power. Landman suggests that when used as a description, "*globalisation refers to the increasing interconnectedness of the world across all aspects of life*" (Landman, 2000, p. 220). Yet, at the same time, the term globalisation can be used to describe a cause, i.e. the dominance of capital or the erosion of local communities, as well as an effect, i.e. the world-wide spread of Western-based culture (Landman, 2000).

In addition to the political dimension, there is also an economic dimension, which is determined by a number of sub-dimensions (i.e. trade, investments, financial markets and actors), and there is a technological dimension, which in itself has an increasing impact on both the social and political dimension, as this thesis will show. Castells (1998) points out that the difference between the world-wide economy and the global economy is that the global economy has the capacity "*to work as a unit in real time on* *a planetary scale*" (Castells, 1998, p. 92). This includes not only just-in-time production and delivery but also information flow without barriers. Until the 1970s, the world-wide economy was always trying to overcome limits of time and space. The late 20th Century brought a change by means of a new infrastructure provided by Information and Telecommunication Technologies (ICTs). Traditional boundaries, such as borders, have become more permeable and easier to penetrate.

Since globalisation has stirred this global economic, social and technological interdependence, the global market place is, and becomes, even more divided into areas of the world that:

a) now progress towards the so-called knowledge-based economies
b) now mimic their previous forms of industrial-based economies
c) and those remaining that are being left out altogether.

Further progress in areas of ICTs, and also in transportation has already contributed to the so-called 'death of distance' (Cairncross, 1997). Shrinking costs of global transactions and of global transportation have fostered a globalised economy, not just for major corporations, but also for individuals. With only a few mouse clicks, a European can now order a product in the US or in Asia, as long as language is not a barrier. And even here one can witness a major shift as language barriers within the areas of e-commerce are shrinking, and as website localisation[2] has become a common standard requirement for the global players.

However, there are still limits to globalisation. The first one becomes apparent when reiterating the fact that globalisation is not fully global as of yet, at least in economic terms. Barriers still exist in forms of limits to capital flows (currencies, banking regulations), (im-)mobility of labour due to immigration restrictions, *etc.* Also, one still witnesses technology export restrictions to a certain set of countries (i.e. Cuba, North Korea) that are either the forgotten legacy of the Cold War or simply the vested

[2] Localisation is an industry term referring to the 'translation' of software, technical documentation, websites etc. into different languages. It is called localisation, as opposed to simply calling it translation, as localisation goes beyond the translation process and comprises of a full service (including translation of graphical user interface strings, code and so on). The focus is on providing a fully-fledged product that is ready for new market entry.

interest of leading nations. In these areas political actions are based on power, that is, states still exercise their historically-rooted hierarchical power in order to achieve desired outcomes (King, 1986). Also, and in order to be precise, one has to acknowledge that 'global' trade is not global yet either. Only 20% of all worldwide produced goods are subject to international trade and only 30% of the global population participates in it. Eighty five percent of the world-wide trade happens between North America, Europe and Asia (The World Bank, 1999), which are at the same time the main R&D areas not only for ICTs, but also for other, new key technologies such as biotechnology, nanotechnology and synthetic biology.

The 1998/99 World Development Report highlights three main issues that require attention in order to better comprehend the long-term effects of globalisation, especially in regard to knowledge and development. The first issue concerns the results of the world economy that now becomes more integrated and global, thus leaving nation states with little leverage on global trends. Moreover, "[m]*ultinational corporations today dominate the global economic landscape: a third of world trade is now between multinationals and their affiliates*" (The World Bank, 1999, pp. 22-23). A country with none or only a few of these global players is clearly disadvantaged and dependent on both international trade regulations (i.e. WTO) and the good will of the other nations. Landman (2000) argues that whether globalisation threatens traditional nation states is an empirical question that requires "*systematic comparative analysis*" (Landman, 2000, p. 220) that can be studied in various ways, for instance by looking at transnational policy networks, political diffusion or universal global rights. However, the implications with regards to knowledge are two-fold: business power differs from the power of a nation state (King, 1986), thus giving multi-nationals a greater control of their intellectual capital and assets and in doing so leaving less leverage, and potential bargaining power, to the traditional nation state, or in the case of the European Union, to a still forming multi-national polity (Héretier, 1999). What this might mean to key technologies, such as biotechnology or nanotechnology will be discussed later (Chapters 4 and 5).

The second issue is that the share of high-technology industries in total manufacturing has grown in nearly all OECD countries. It is estimated that more than half of GDP in these countries is based on the production and distribution of knowledge itself (The World Bank, 1999). This, obviously, has implications for the composition and thus requirements of the work force. The World Bank estimates that in the US alone the percentage of workers engaged in producing and distributing knowledge is higher than those of workers that are (still) engaged in making physical goods. Although these indicators are mainly valid for OECD countries, they still provide useful insights about current developments and the increasing importance of knowledge for both organisations and nation states. When measuring the knowledge output - a popular indicator is the number of patents issued - one can observe a skyrocketing in the past decade. For instance, in the four years between 1989 and 1993 the number of patent applications worldwide had increased by 43 percent, or from 1.4 million to 2 million according to the World Bank. Somewhat slightly different figures are shown by the World Intellectual Property Organisation (WIPO), see figure below:

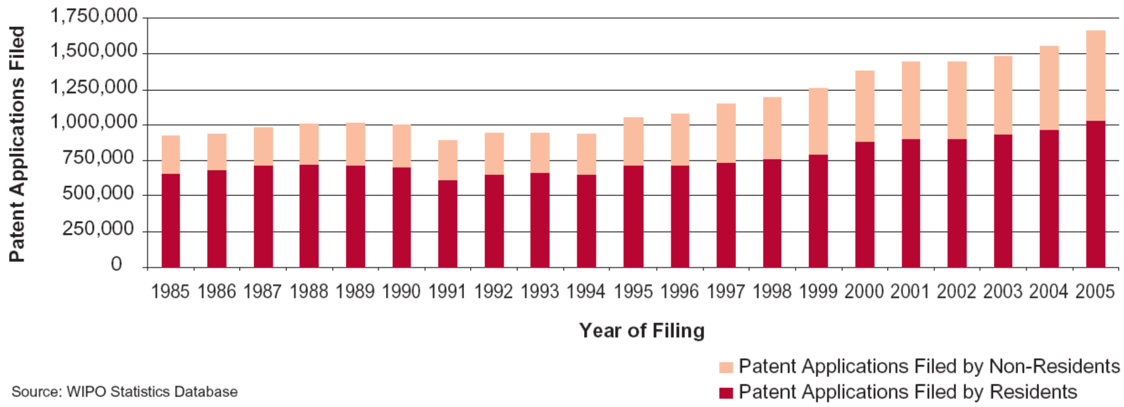

Figure 1: Worldwide patent filings by year of filing (WIPO, 2007, p. 10)

Nonetheless, one can see that patent filing nearly doubled in the years between 1995 and 2005. Looking at the countries responsible for the majority of worldwide patent filings, it becomes very clear that globalisation and knowledge output are not global. The table below shows that only five out of the top 20 countries of filing patent applications are nations that are regarded developing nations. By looking at the top five countries, responsible for 77% of all patent applications, only China is not regarded as a country belonging to the first world[3].

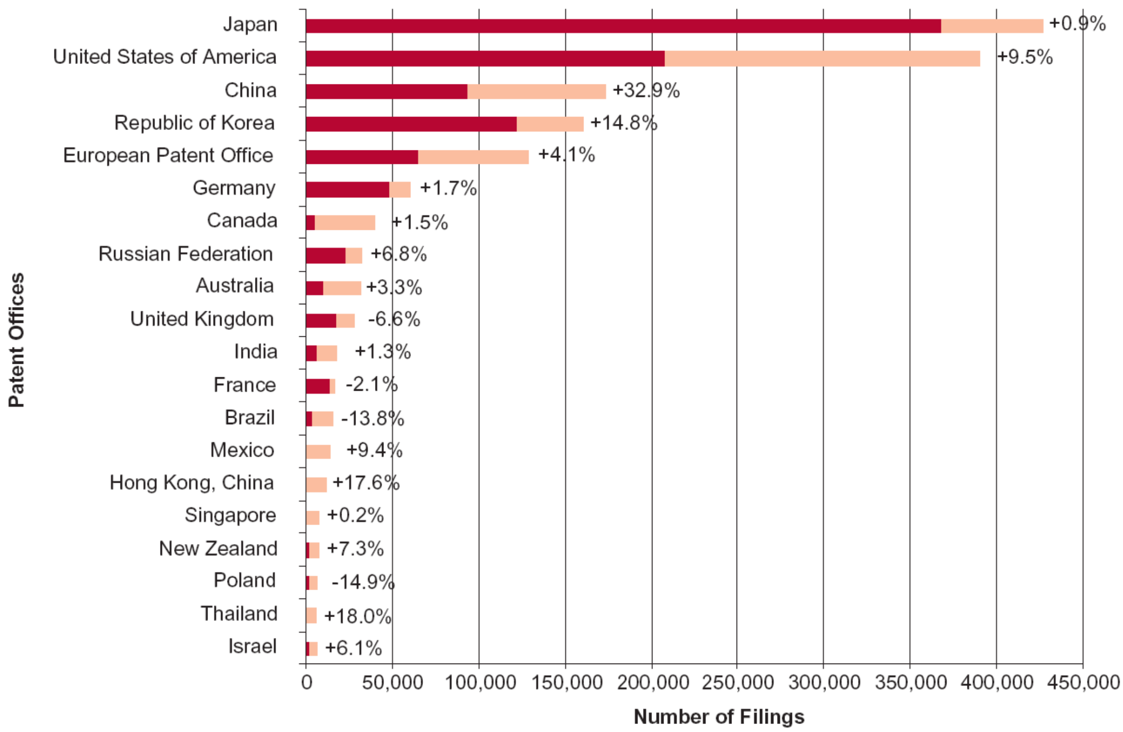

Figure 2: Top 20 patent offices by country of origin (WIPO, 2007, p. 12)

The third and last issue concerns the speed by which ICTs and other new key technologies are advancing. A popular example to illustrate this growth rate in regard to technical knowledge is the comparison with developments in the aircraft industry. *"It has been said that if the aircraft industry had evolved as spectacularly as the computer industry since the mid-1960s, by the mid-1980s a Boeing 767 would have cost $500 and could have circled the globe in 20 minutes on 20 liters of fuel"* (The World Bank, 1999, pp. 22-23). The crucial component in this development is that the ICT revolution and the strides that have been made in other, new, technology areas fosters the creation of new knowledge by equally providing inventors and innovators with critical input; that is, quick access to knowledge. The most important aspect is the fact that knowledge can now be disseminated at an unparalleled scale around the globe at ever decreasing costs.

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[3] Although this might change in the near future, considering the immense economic progress made.

One point, above all, is clear: countries that are not able to utilise these current trends will fall behind those who encourage it. Failing to promote investments in, and utilisation of, both global and local knowledge will no doubt result in increasing knowledge gaps between the leading countries and the laggards. Those who cannot participate when, for instance, a new set of converging technologies is introduced can normally also not participate in the decision-making process that is to set out the rules for regulation, industry norms, environmental standards, *etc*. What this means in the context of this research is that, while the most developed nations are already struggling with keeping up with technological process and required regulative norms, the least developed nations are so far removed from key technology areas that the inclusion of these states into a global knowledge framework seems to be impossible. Yet, as climate change has shown, and as nanotechnology might prove, these countries are not protected from undesired impacts. Bangladesh as a country does not belong to the circle of countries that are the main emitters of CO_2. Nevertheless, if rising water levels are indeed a result of global warming Bangladesh might have to pay for the 'sins of other countries'. The same might potentially be true in the case of nanotechnology.

According to Hoogvelt, globalisation has "*rearranged the architecture of the world order*" (Hoogvelt, 2000, p. 358) in a sense that economic, social and power relations have been altered. Hoogfelt argues that perhaps 20 percent of the world population, i.e. those that are 'bankable', enjoy the benefits of globalisation. Another 20 – 30 percent have to face insecure forms of employment and are therefore unlikely to reap all the benefits that globalisation offers to their 'bankable' counterparts. The remaining, larger parts of the world population (circa 50-60 percent) are "*already effectively excluded from the global system"* (Hoogvelt, 2000, p. 358). If this is already the case, then questions arise as to what can and what needs to be done in order to accompany, steer and possibly mould these developments so that the outcome is a preferable one.

Furthermore, the ever increasing complexity of the technological and economic realms, of a globalised world and also of society itself may ask for different, if not new, modes to govern a modern political realm that not only wishes to face but also foster and nourish these transformations. This is one of many challenges states face if they wish to address the increasing number of internal and external challenges (Pierre, 2000). However, there are serious issues that need to be associated with faster, and ever increasing levels of knowledge and expertise and its resulting dependencies. If there is indeed an increase in the complexity of how the globalised world functions, should not any forward thinking government also increase its focus on learning, knowledge acquisition and distribution? If everything is indeed becoming more technologised, complex and more difficult to comprehend, should observers not be able to witness the upsides and downsides to this development, i.e. people, organisations or economic areas that either can or cannot cope with these developments? And if so, will inaction by governing bodies immediately lead to a more polarised society or even world?

An alternative view, according to Stevens *et al.* (2002), suggests that the above might not be true at all. The proponents of this point of view argue that more sophisticated technology does not automatically require higher technical skills, as lessons from previous technological advancements suggest. For instance, 50 years ago a car mechanic's knowledge had to comprise of how to take apart certain components and how to put them back together. Today, all they need to know is which components need to be replaced, and by what costs (Stevens, Miller, & Michalski, 2000). Translating this view into key technology areas, such as ICTs, biotechnology or nanotechnology could potentially reveal whether the aforementioned global and technological changes are indeed as pervasive and as complex as suggested. Chapters Four and Five will pay special attention to both knowledge-intensive and key technology areas and what this means from a (hands on) knowledge perspective. Assuming that government and policy makers have an interest in steering the aforementioned developments in order to reap the best possible benefits for their nations and populations, a closer look is required at the technological, societal and political dimension of the global change.

2.1.2 The change of the technological realm

Before speaking of technological change in general as well as of most recent technological advances, it is useful to define what is commonly understood as technology. A definition from a dictionary suggests that technology is "*[t]he practice, description and terminology of any or all of the applied sciences which have practical value and/or industrial use*" (Walker, 1999). Ernst and O'Connor (1989) correctly pointed out that:

> technology cannot be reduced to machines. It has to do with certain kinds of knowledge, which allow the adaptation of means to ends. Part of this knowledge is embodied in machines, but most is not. It is embodied elsewhere – in the brains of people, in organisational structures and behavioural patterns, which in turn are conditioned by the strategies of different social factors and their patterns of conflict and co-operation (Ernst & O'Connor, 1989, p. 20).

One can therefore assume that technology does not only consist of tangible but also intangible elements or parts. These can be found, for instance, in the aforementioned patents or in the skills and knowledge a company's workforce holds. But also marketing, product and consumer research play an increasing role. At the same time, it needs to be understood that technological change does not automatically mean that the best technology or product will lead the transformation and dominate the market. A number of cases have shown that there are also other contributing factors that steer technological development and change**.** For instance, an often quoted example is that of Betamax vs. VHS in the area of consumer electronics. At the time, it was acknowledged that Betamax was the technologically superior product, yet VHS dominated in the end (Wielage & Woodcock, 2003)[4].

Technological change is defined as "*the generation and diffusion of new technologies*" (Ernst & O'Connor, 1989, p. 20); that is, the creation of new technology, its distribution, and its acceptance by the users. Only the acceptance of new technology

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[4] A more recent example is that of the new DVD 'format war' between Blue Ray and High Definition Disk (HDD). In both cases, technology itself was not the deciding factor, others, such as support pledges by other companies or entire industries (also called vendor lock-in) may turn out to be of greater importance.

heralds the substitution of 'old' technology with the new one, although this has to be seen as a process that often allows the simultaneous existence of both technologies for a certain amount of time. Technological change, especially nowadays, is driven by, and is a core element of, competition. Yet, it should be pointed out that in certain circumstances, as recent examples have shown, the non-commercial sphere of society can also contribute to technological change. Most notably seen in the international 'Open Source' movement with its main goal the non-commercial use, development and distribution of source codes used for the development of computer applications. Their main aim is to provide free, non-commercial software: "*The promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in*" (Open Source Initiative, 2007).

Technological change and development itself has been subject to intensive research; for instance the historic perspective of technological change and industrial development in Western Europe has been explored, amongst others, by Landes (1999a; 1999b), Mokyr (1990) and Kondratieff (1926), who approached it by researching different economic cycles. Today, both the first and second Industrial Revolutions provide insights about the importance of technology and innovation and the subsequent spread and use of knowledge. In this regard, Castells holds that "*the ability or inability of societies to master technology, and in particular technologies that are strategically decisive in each historical period*" (Castells, 1996, p. 7) largely shape their destiny. Since the Industrial Revolution, the pace of technological development and innovation has increased heavily and the ability to either lead or keep up with technological developments became a major determinant of economic competition. In terms of this thesis, the Industrial Revolution is an important concept that situates technological change (i.e. within the Kondratieff cycles), as it provides insight into the importance of knowledge (i.e. in the context of technological change). Landes (1999b) discusses the role that knowledge played as part of the Industrial Revolution in detail. In addition to the role of education, the recruitment of expert skills and knowledge, sometimes achieved even through means of seduction and bribery, was a vital part. The idea of preventing the loss of what is now called 'intellectual capital' was not new at the time (Landes, 1999b). The importance of knowledge since then has only increased, while globalisation led to an increase in the pace of technological innovation. These developments, including the increased corporate focus on knowledge, can nowadays be tracked by a popular indicator that is used to describe knowledge output: patents.

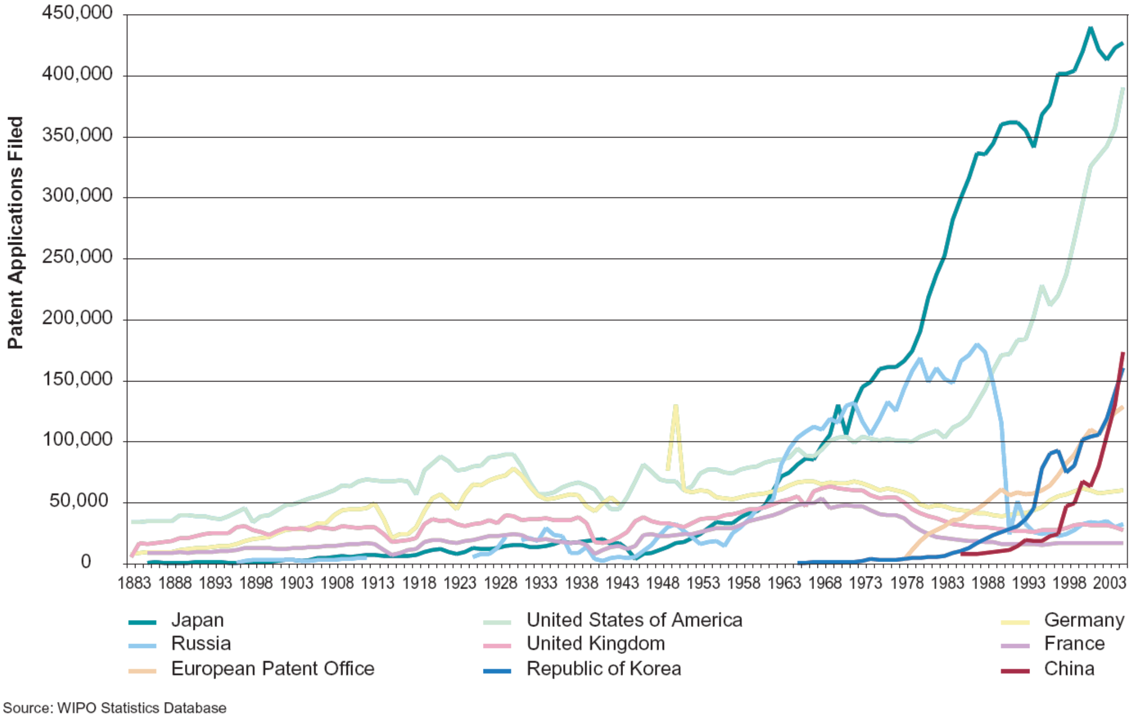

Figure 3: Evolution of worldwide patent filings (WIPO, 2007, p. 11)

The figure above shows that growth was very modest until the 1960s. The average annual growth rate was only 1.99% from 1883 to 1959 and only four countries (USA, Germany, UK, and France) were responsible for the majority of the patenting activities in that period. This changed in the 1960s with Japan and the Soviet Union entering a stage of economic progress, and their subsequently increased filings of patent applications. Japan has dominated the league table ever since, whereby the Soviet Union's record of application filing took a sharp decline with the fall of Communism in 1989/90. Since the 1980s, further countries joined the leading nations, most notably Korea and China. Between the 1960s and 2005, the annual growth rate had increased to an average 3.35%. In 1977, the European Patent Convention came into force. Since the European Patent Office was not intended to substitute for the national offices, it offered applicants the choice between filing patent applications nationally (as before) or through a newly available regional route. This explains the decline of filings by Germany, France and the UK (WIPO, 2007).

Over the last two decades, technological changes have also entered the personal sphere of every individual (at least in the developed world) at unprecedented speed and depths (Beck, 2000). In the grand scheme of things, it does not really matter as to whether a cycle or technological development, or a phase of economic development lasted a few years longer or less, as Hall and Preston's (1988) and Haggett's (2001) figures have shown. What is important is that, over time, one can identify patterns and key technological drivers that made an era distinctive. Here, the Kondratieff waves are an important tool. Today, one can once again witness one of these distinctive eras: information technologies converging with chemistry, biology, physics, medicine, mechanics and others in order to drive new technological change that translated into the rise of new technologies. What these new technologies have in common is that they all are knowledge intensive and expertise dependent.

Today, when speaking about technological change, information technology - or the semiconductor industry, as described by Haggett (2001) and Hall & Preston (1988) - is the most obvious technological branch that comes to mind; yet there are additional technological areas that have gained importance. According to Castells, information technologies can be described as "*the converging set of technologies in microelectronics, computing (machines and software), telecommunications/ broadcasting, and optoelectronics*" (Castells, 1997, p. 30). He also includes the area of genetic engineering and "*its expanding set of developments and applications*" (Castells, 1997, p. 30). Amongst other areas, information technologies can be categorised into the following[5] sub-categories:

- Telecommunications/Broadcasting
- Computing
- Microelectronics[6]

[5] The above list is by no means exhaustive.
[6] Microelectronics refers to the study and manufacturing of microelectronic components (i.e. digital circuits, conductors).

- Optoelectronics[7]

Taking Castells' point of converging technologies into account, other new, and at the same time, potentially controversial technologies that have emerged in recent years. These are, amongst others:

- Biotechnology
- Genetic Engineering
- Nanotechnology
- Synthetic Biology

Much has been written about biotechnology (Fukuyama & Wagner, 2000) and genetic engineering (Goodman, Heath, & Lindee, 2003), and recent debates about genetically modified foods (Bonny, 2003), substances and additives to food have sparked an interest amongst consumers, NGOs, and social scientists alike (Marris, 2001). Synthetic Biology is the most recent addition to the list of emerging technologies. Its aim is to combine biological research with engineering in order to either re-write existing, or design new, biological systems or components. Within the Life Sciences, and by combining these new emerging technologies with existing and future information technology, knowledge and its components (data, information) will play an increasingly important role, and will therefore be discussed in the next chapter. What distinguished these four technologies from others is that they are converging sets of a multitude of technologies. In other words, they are not stand-along technologies; their main characteristic is that they are built upon the complex interactions between a numerous technologies linked by advances in information technologies. Out of these four examples, nanotechnology has been chosen to represent the new key technologies for the purposes of this research. As of now, no one knows what this new technology will bring, nor what advances and riches, which risks and perils; Mokyr put it as follows: *"[t]he essence of technological progress is its unpredictability*" (Mokyr, 1992, p. 301).

[7] Optoelectronics refers to the study and manufacturing of electronic devices that deal with the sourcing and use of light (i.e. photo-diodes, integrated optical circuits).

2.1.3 Economic changes

The global and technological changes of the past decade came hand in hand with changes to the economic realm. Castells calls the new economy informational and global in order to identify its distinctive features and to emphasise its intertwining characteristics. He points out that it is informational because productivity and competitiveness depend on a firm's (or even region's or state's) "*capacity to generate, process, and apply efficiently knowledge-based information*" (Castells, 1998, p. 66). A main feature of the changes of economic landscape triggered by the rise of the semiconductor industry (often also called ICT revolution) is that it has vastly increased the marketability and value of commercial information by reducing the transmission costs of information. The results of this are new patterns of interaction between players, be they of economic, political or societal nature. The new economy is also global, according to Castells, as its core activities of production, consumption and circulation, "*as well as their components (capital, labor, raw materials, management, information, technology, markets) are organized on a global scale, either directly or through a network of linkages between economic agents*" (Castells, 1998, p. 67).

The main features, however, are the information technology industry and its sub-industries; they provide the necessary basis for the new economy. In taking all three points together (informational mode, global focus, new information technologies), one reaches a new and distinctive economic system. Although, information and knowledge have always been decisive elements for economic growth, only the emergence of more flexible information technologies made it possible for information itself to become a product of the production process. Popular examples include corporate intelligence gathering (i.e. country and market reports) and information processing about consumer behaviour (i.e. data mining of available consumer data). Based on research undertaken already in the 1980s by Freeman and Monk, Castells gathers that "*the products of new information technology industries are information processing devices or information processing itself*" (Castells, 1998, p. 66).

Information technology, accompanied by the rise of and ever cheaper access to, information, is the new and main "raw material" and core focal point of the knowledge economy. This development, in turn, also contributed to the rise of a new social class of people who have access to information, as opposed to the information 'have-nots'. Advanced high-tech communication systems, access to open markets and minimal trade barriers fostered the gap-building between the information haves and the have-nots on a global scale. Due to its nature, knowledge as a means of production also fostered new developments that have forced businesses to re-think their strategies, as knowledge as a commodity is expensive to produce, but relatively easy to reproduce, copy or to steal (Stevens *et al.* 2000). Over the long term, this may pose substantial issues to access to knowledge, especially when it is of a corporate nature. What is more, knowledge and expertise are inherent in corporate patents, which is also on the rise as shown in Figure 3. This, in turn, may also have long-term impacts on both policy-making, which is depend on using knowledge when making policy-changes, and public participation, as the public's access to corporate knowledge cannot be guaranteed.

This knowledge-based economy is, however, also far more complex than its industrial predecessor, "*as the number of distinct products, producers and consumers increases, the knowledge economy introduces more variety*" (Stevens, Miller, & Michalski, 2000, p. 13). Castells concludes that: "*Profitability and competitiveness are the actual determinants of technological innovation and productivity growth*" (Castells, 1998, p. 10). Hillner (2000) argues in a similar vein and suggests that there are a number of factors to be taken into account; two of them are of particular interest here:

- The abilities of universities and research facilities to train skilled workers and/or to develop new technologies.
- The presence of established companies and multinationals to provide expertise and economic stability (Hillner, 2000, p. 259).

Today, universities and research facilities have started to go beyond the sole provision of education and innovation by also putting the results of their innovation into practice. This so-called 'knowledge transfer process' is supported by experienced professionals ensuring that innovations make it into the market. The role of knowledge transfer receives even more attention when linked to the access to domain specific expertise (see also Chapters 3.1.5 and 6.3), as it provides an access route to expertise outside the corporate world. The World Bank also provides numerous examples showing that knowledge itself has been the decisive factor in regard to economic development. For instance, the Soviet Union has accumulated more capital - as a share of its GDP - between the 1960s and 1980s than Hong Kong, South Korea, Singapore or Taiwan by improving the education of its population.

> Yet the Soviets generated far smaller increases in living standards during that period than did these four East Asian economies. Perhaps the difference was that the East Asian economies did not build, work, and grow harder so much as they built, worked, and grew smarter. Could knowledge, then, have been behind East Asia's surge? If so, the implications are enormous, for that would mean that knowledge is the key to development—that knowledge is development (The World Bank, 1999, p. 19).

When speaking in an economic context, the word knowledge receives a different accentuation than, for instance, in philosophy. The word knowledge, as used in the term 'knowledge economy' or 'knowledge-based economy'[8], refers to information and knowledge as a commodity, such as the already discussed patents, or technological know-how and intellectual capital. Philosophical questions, such as 'Does knowledge exist?' matter less for corporations than the fact that knowledge is seen as an asset that can and needs to be translated into capital gains.

2.2. Changing society

Speaking in historical terms, a society's ability to master technology has always been strategically decisive (Castells, 1996). Furthermore, the extent to which societies are able to use technology exemplifies their capacities to transform themselves. In the upcoming information/knowledge society, access to knowledge, the ability to comprehend and use it as well as knowledge accumulation will undoubtedly be the main feature (Stehr, 2002).

[8] For years now, *The Economist* has been using the terms knowledge-based economy and knowledge society (The Economist, 2006), whereby others prefer to use information society, information age or knowledge age. For a discussion of information vs. knowledge society, see Chapter 2.2.1 and 2.2.2.

> For countries in the vanguard of the world economy, the balance between knowledge and resources has shifted so far toward the former that knowledge has become perhaps the most important factor determining the standard of living—more than land, than tools, than labor. Today's most technologically advanced economies are truly knowledge-based. And as they generate new wealth from their innovations, they are creating millions of knowledge-related jobs in an array of disciplines that have emerged overnight: knowledge engineers, knowledge managers, knowledge coordinators (The World Bank, 1999, p. 16).[9]

This, however, also poses challenges with regards to a society's ability to utilise information and knowledge. Stehr (2002) points out that modern knowledge-based societies are, to a large extent based on structural changes of their economies and that the "*source of economic growths and value adding activities increasingly relies on knowledge*" (Stehr, 2002, p. 3). In order to understand the nature of knowledge that is required to keep a society moving forward, be it economically or culturally, it is necessary to distinguish various forms of knowledge (for a detailed discussion of knowledge, see Chapter 3). There is knowledge that can be acquired by simply buying it; various organisations have already specialised in providing knowledge as a service. Other forms of knowledge cannot be bought. This includes knowledge that requires a long-term process of individual or organisational learning. Organisations are able to absorb knowledge in a similar fashion to individuals by constantly repeating and refining tasks (Nonaka & Takeuchi, 1995). And, of course, there is knowledge that needs to be created first. In addition, and before going into more detail, one needs to acknowledge that there are also various forms and types of knowledge gaps. These exist across all societal levels, across nations, across the developed world and across developing countries. The term knowledge gap has two main usages. The first refers to knowledge that an individual does not have, no matter whether the individual is aware of 'not having' the knowledge or not. The second usage refers to the global knowledge

[9] One topical example can be found in the already mentioned area of knowledge transfer, often instated to foster the transition of R&D results (for instances, of universities and their institutes) to market.

divide. The assumption here is that knowledge gaps increase the more the developed world advances and leaves the underdeveloped nations behind (UNESCO, 2005).

Today, it is commonplace that by acquiring, absorbing, and communicating knowledge one can stimulate economic growth and thus foster human well-being in general. Reducing knowledge gaps is, however, easier said than done. At a micro-level, for instance, one can consider the improvement of educational conditions for a local community; this seems feasible and manageable. Bringing developing countries closer to their counterparts in the first world is far more complicated (UNESCO, 2005). Even by closing gaps with respect to technical knowledge, for instance, there is still the matter of various other forms of knowledge (The World Bank, 1999). Furthermore, and apart from the fact that often even the computer age has still not yet arrived in many of the developing countries, existing societal structures may have seen little change over the centuries.

In order to shed some light on changing societies, in particular, the current level of societies' information and knowledge exposure, two popular concepts shall be briefly explored: the concept of information societies and that of knowledge societies. It should be noted, however, that although both concepts are different in their respective theoretical approach, both terms are often used interchangeably, be it in academic terms, or by the press or media.

2.2.1 Information Societies

As previously discussed, societies are constantly changing and one current force of this change is information. According to Krohn, the term information society "*relates to the pervasive influence of computer-based networks and thereby the globalisation of information, communication, and control technologies. It assumes that collecting, copying, storing, transmitting, incorporating, manipulating, simulating, and managing information about every aspect of collective and individual life penetrate and shape all these aspects"* (Krohn, 2001, p. 8139). Webster refers to information as a "*defining feature of the contemporary world*" (Webster, 2001, p. 7464). Terms such as *information society* or *global information economy* are a logical response to the new found importance of information and are easily backed up by facts such as new media, products, economic channels and so forth that have developed since the rise of new ICTs. Webster admits though it has become popular to describe Western societies as information societies, yet the term *information society* is not without criticism. This is due to its link to information technologies that it may be perceived or suggested that an information society is a novel type of society or a novel system altogether. Opponents to this view suggest that societies have not changed in their basic patterns, only activities themselves have become more informationally saturated (Webster, 2001). In order to establish quantitative measures of an information society, Webster (2001) suggests looking at different categories that are being impacted by recent technological developments:

- Technological
- Economical
- Occupational
- Spatial
- Cultural

Advocates of technological conceptions, such as McLuhan (1964), Toffler (1980), and Negroponte (1995) suggest that technological innovations since the late 1960s will have such a profound impact on society that it will lead to a reconstruction of the social world. Proponents of determining the economic value and impact, such as Machlup (1962) and Porat (1978), suggest that by calculating the contribution of information business to the GNP, one can determine when an informational economy has outgrown an economy based on manufacturing and agriculture and thus determine when a society has become an information society.

According to Webster (2001), sociologists mostly favour the occupational approach of defining an information society. This approach suggests that today's societies can be classified as an information society when information based occupations are in the majority and "*thus the information society is said to have arrived when clerks, lawyers and comedians outnumber colliers, steelworkers, dockers and builders*" (Webster, 2001, p. 7465). According to Bell (1973), the decline in manufacturing and rise of the service sector heralded the triumph of the white collar – and as such informational –

work over manual/manufacturing labour. Other studies also suggest that work is becoming more 'knowledge intensive' (Lash and Urry 1994), and that activities such as design, media and management requiring more intelligence and education than hitherto (Reich 1992, Leadbeater 1999).

The spatial component played a major role in Castells' (1996-98) work. This approach focuses on information networks, locations, time and space. In short, one can argue that electronic highways lead to a new emphasis on the flow of information, thus altering the time-space relations by eliminating the constraints of time and distance. This includes information sharing across continents without the need to physically move information or people that hold information, thus giving corporations and other organisations the opportunity to conduct their business on a truly global scale. Landes (1999b) described how experts were moved from location to location during the Industrial Revolution, often at great expense. This, now, has become obsolete due to the availability of cheaper information sharing options. Although the above definitions illustrate the rising importance of information, none of them say anything about the impact information has on them.

Explaining the concept of an information society by means of the cultural approach might appear as the most obvious, but Webster argues that it is "*the least amenable to measurement*" (Webster, 2001, p. 7465). Access to globally available cultural goods, such as music, fashion and popular literature has become easy and could also easily be measured in terms of sale or market penetration. Yet, using these measures to determine the state of a society in order to define whether a society has become an information society remains questionable. Indeed, such an approach might be better suited to quantitatively measure the (economic) progression of globalisation by analysing market penetration of globally available products. Webster (2001) argues that there is a tendency to use quantitative measures in order to describe and explain qualitative change. "*The central criticism is that quantitative indexes of the spread of information and information technologies cannot be interpreted as evidence of deep-seated social change. On the contrary, they can be regarded as the consolidation of established patterns of interest and control*" (Webster, 2001, p. 7466).

There is another concept attempting to explain information societies: theoretical knowledge. According to this concept, "*an information society is one in which theoretical knowledge takes precedence over the practical. Humans throughout history responded to conditions as they found them, while today things are organized, harnessed, and controlled by starting from known theoretical principles such as laws of motion, chemical reactions, and the stress capacities of metals*" (Webster, 2001, p. 7466). The emphasis on theoretical knowledge equals an emphasis on qualitative rather than quantitative change. But similar to the cultural approach, measuring theoretical knowledge must also explain its assumed penetration of society. It has been shown that knowledge output is often measured by using patent statistics. Yet, using this measure would not say much about how a society has been transformed, who the participants in this information society are and who the opponents are. Although Bell (1973) was the first to point to the primacy of theoretical knowledge, it was Stehr (1994) who defined a society in which theoretical knowledge determines nearly all activities - the *knowledge society* (see also 2.2.2).

To summarise, the majority of criticism revolves around the assumption that there has been a systemic social change that can be proved by employing quantitative measures, which determine the growth of the role of information on various aspects of the global world, the economy, technology itself and on culture and society. Earlier attempts to explain changing societies include Bell's concept of the *post-industrial society (1973)* or Schiller's *informationalised capitalism* (1996). The term post-industrial society refers to a society where manufacturing has been replaced as the main economic driver by a service-based industry. Schiller's concept of informationalised capitalism attempts to explain advanced capitalism by focusing on the information explosion (Webster, 2001).

Similar to Bell's concept, the notion of an information society has received much attention. Webster, however, suggests that it has only limited value for the social scientist and Castells goes even further and suggests abandoning the notion altogether (Webster, 2001; Castells, 1998). Generally, there are no objections to the claim that societies are changing. It is, rather, the way of explaining it and the extent of change to society that has been criticised. Information itself has not altered, thus far, the way societies are organised, albeit it has changed the way the advanced economies function. Webster concludes that "*it is ironic that the most persuasive conception of an information society, that which centres on the role of theoretical knowledge, is the least examined by the information society adherents*" (Webster, 2001, p. 7468). Therefore, the concept of information societies as it stands today, does not seem suitable to explain the potential impact of both the increasing importance of information and the increasing scope of available information. Questions, such as how does the public cope with increasing complexity in an information society are not answered.

2.2.2 Knowledge Societies

Contrary to the above-discussed concept of information societies, the concept of knowledge societies "*emphasises in a complementary way the problem and strategies of making sense of information. The knowledge work of researchers, experts, analysts, and users depends much on and contributes to information – but what it makes this work important is it use of theories, models, scenarios, evaluation criteria, decision strategies, experimental designs, and implicit experience in order to establish bits and pieces of orientation and certainty*" (Krohn, 2001, p. 8139). This means, as opposed to the concept of information societies where computational power and ICT are the determining forces, knowledge societies are determined by the 'process of sense-making' of information (see also Chapters 3.2.1 and 3.2.2). By referring to Earl (1996), Krohn highlights a new risk that decision-makers face: the complexity and opaqueness that comes with infinite amounts of information available and the increasing need to know about information itself.

Thus, one of the core points of the concept of a knowledge society is dealing with uncertainty, insecurity and ambiguity. The assumption is that the more information is available, the more difficult it becomes to condense this information into reliable and usable knowledge. "*Rather, actors are left alone with the choice between doing anything or nothing – except where there is an agency promising to be specialised in knowing how to read and use information*" (Krohn, 2001, p. 8140). In recent years, knowledge operation has, to a certain extent, been standardised and integrated into expert systems. By using filters and algorithms (knowledge operation) relevant data, information and knowledge is being made accessible through specialised systems (expert systems). This enables the user to focus on only the relevant and pertinent parts instead of having to go through large amounts of data and information or complex bodies of knowledge. For instance, large corporations use these systems to distil information according to the target audience. Thus, executive staff receive different information from, for instance, operational staff. Despite this being a help to decision-makers, especially within large corporations, there are still issues that exist between modelling and standardising processes and the use of expert systems in their appropriate context (Krohn, 2001). Although advances have been made by using expert systems, their application is still limited. For instance, expert systems can be used within organisational contexts at a level that can support even larger, global corporations. However, it cannot be used to support or compute decision-making at a societal or nation-state level. It is not that the required computational power is limited, but rather that decisions at that level are far too complex to use expert systems. This, in turn, mirrors one of the core arguments of the knowledge society concept: complexity.

There are three areas that need to be discussed when speaking about the concept of knowledge societies:

- Knowledge work
- Expert knowledge
- Science and society

Knowledge work cannot be simply put into categories such as those previously used to define work, i.e. manufacturing, agriculture and so forth. Knowledge work, in general, is rather a concept that refers to general activities that are based on using mental capabilities, such as analysing, interpreting/evaluating or teaching. Cortada (1998) argues that knowledge work has been around for thousands of years, and knowledge workers[10] for even longer. "*What is very new is the categorization of these people, activities and tools into a discrete field – knowledge work …*" (Cortada, 1998c, p. 3). Often, problem selection, definition, and solution or communication with partners, clients and stakeholders is core to knowledge work and to the generation of wealth based on knowledge rather than natural resources. To put this into context, an example from the area of consumer electronics will be used. For instance, a company releases a product that is close to that of its competitors in regard to performance and quality. In order to ensure that the successor product becomes superior to that of the competitors, 'knowledge work' is required. This knowledge work can comprise of a number of tasks ranging from integration of lessons learned to using feedback from users and their experiences. These tasks rely not only on the identification and definition of problems, but also require the conceptualisation and provision of solutions and communication with partners and customers.

Krohn (2001) stresses that there is a "*complementary aspect to the economic and organizational characteristics of knowledge society. Certainly, knowledge would not have become a predominant resource if it could not become transformed in marketable goods and services. … The more society relies on knowledge, the more it navigates into a dynamic of change. To understand, describe, predict, construct, and control this change becomes illusory–simply because of lack of knowledge. This is exactly the reason why knowledge experts (Jasanoff 1990) and symbolic analysts (Reich 1991) are needed and expected to create islands of certainty to allow orientation and planning*" (Krohn, 2001, p. 8141). The dependency on expertise appears to be one of the defining points of a knowledge society, and also one of the main differences to the concept of an information society**.** In other words, this means that the more knowledge-intensive technology becomes dominant, and the more resulting applications penetrate day-to-day life of society, the more society itself becomes dependent on expertise. This expertise dependency is a direct result of the knowledge-intensity and complexity that comes with many of the new, key technology areas, such as biotechnology, genetic engineering or nanotechnology. This increasing uncertainty and ambiguity of, and

[10] Similarly to the concept of information society (vs. knowledge society), some authors prefer the term information workers, for instance Porat (1998).

about, available information is the central problem that individuals as well as organisations and governments face in the future. This is one of the central arguments of this thesis. The concept of knowledge societies seems more suitable to answer these questions than the concept of information societies.

2.2.3 Summarising societal change

As shown in the above discussion about information and knowledge societies, the key element that will enable future change is not information alone, be it qualitatively or in quantity, but complexity that is inherent in both newly-found theoretical knowledge and new areas of technological development and its accompanying uncertainty and ambiguity. As demonstrated, knowledge work itself is not that new, but what has changed is the vast increase in the numbers of areas that are converging. Commonly known knowledge workers, such as teachers, priests, or doctors or shamans have been around for a very long time. But until now, knowledge work has often been isolated to limited areas, such as teaching or practising medicine.

With the rise of the ICTs, knowledge work expanded into many new areas, with many of them being depended on the new ICTs. Without the recent advances in semiconductor development, new fields, such as, biotechnology, genetic engineering or nanotechnology could not have emerged as they did. Similarly, without ever increasing computing power, global warming, as it is known today, may not be as known, or worse, may have never been identified.

Krohn concludes that the "*knowledge society can be interpreted as being exposed to hypothetical assumptions and experiments designed by experts and analysts. While expertise effectively reduces the complexity of the real world for an observer, it inevitably contributes to increase the risks of those who decide to rely on it"* (Krohn, 2001, p. 8142). In other words, new problems arise when society depends on, and is directly affected by, expertise. Not only can society not afford errors, but it also raises questions about who in society decides which expertise is to be used? Should only governments decide on the utilisation of the right expertise? What about opposition and what about ordinary citizens? This increasing complexity has left many unable to deal with the amount of information generated today. In order to utilise much of this newly generated information, society has turned to experts and their expertise.

> The complexity of modem society, the expansion of governmental functions, and the technical nature of most policy problems create enormous pressures for specialization. It is exceedingly difficult, except perhaps in small communities, to be knowledgeable about more than one or two policy sectors (Sabatier, 1988, p. 137).

The definition of what expertise is (see Chapter3.1.5) agrees with Sabatier's argument. This new and resulting dependency on expert knowledge has received already as much attention as it has received criticism and brought about a new 'politics of knowledge' (Cozzens and Woodhouse 1994). A similar view is shared by Edwards (2010). Here, the argument is that the "soft authority of knowledge is ever more important as a force for social change. That's why the politics of knowledge – how ideas are created, used and disseminated – represents a key issue…"(Edwards, 2010). How the realm of politics has changes due to the increasing importance of information and knowledge is the subject of the next chapter.

2.3 Changing politics

> By the mid-20th century, science and particularly nuclear physics, contributed crucial power resources to the US and the SU. In the next century, information technology broadly defined is likely to be the most crucial power resource (Keohane & Nye, 1998).

The aforementioned changes to the global arena and its technological, economic and societal spheres pose a multitude of new internal and external challenges to governments. This is why the role of the political environment cannot be stressed enough (Pierre, 2000). The result of what happens when the state is not only an organising factor but a dominating or even a coercive source of power one could witness before the fall of Communism in Central and Eastern Europe. The economic and technological legacy of those countries now suggests, and also corroborates, the assumption that, thus far only a liberal market democracy can provide the necessary ground for a (relatively) interference free, resourceful and competitive research and innovation environment. Apart from domestic aspects, there is also an international dimension. The history of the Cold War and its opposed blocs has vividly illustrated the impacts of (international power-) politics on the area of technology and its subsequent impact on the economy. By exercising agreed high-technology transfer restrictions towards the Eastern bloc, the West gained decisive advantages in technological development, and therewith a competitive advantage in their economic development and, again, in the area of (power-) politics.

There is no doubt; the changes introduced by the so-called Information Revolution will change the way people live, are educated, work or govern. The increasing use of information technology in the sphere of business or even in the private sphere will profoundly alter relationships that have followed historically grown patterns. Most importantly, governments, organisations and ordinary people have to adapt to the upcoming changes, especially since the number of active players increases. Hence, the political realm is changing. The increase in the number of communication channels, be it at the stage of world politics, domestic, regional or local, and the increase of available information itself will challenge the area politics. As has been shown, there is an increase in knowledge-intensity and in technological complexity and the result is an increasing dependency on expertise. But before investigating this further, a step back needs to be taken in order to shed some light on the starting point of all this, the so-called ICT revolution, as this can be viewed as one of the major turning points in the last century.

The theoretical debate and the literature can broadly be divided into two groups: the so-called 'prophets' of the ICT-revolution and their opponents or critics. According to Keohane and Nye (1998), people such as Peter Drucker, the Toefflers, Ray Kurzweil and Esther Dyson belong to the group of prophets. Many of them predict an end to the hierarchical bureaucratic organisation and that the ongoing ICT revolution "*is creating the 'disintermediation of government', leading to a new electronic feudalism with overlapping communities and jurisdictions laying claim to multiple layers of citizens' identities and loyalties*" (Keohane & Nye, 1998). Both Keohane and Nye have a point in arguing that "*[p]rophets of a new cyberworld, however, like modernists before them, often overlook the extent to which the new world overlaps and depends upon the traditional world in which power depends upon geographically based institutions*" (Keohane & Nye, 1998). In other words, there still will be rules necessary to govern society, no matter its level of use of technology. Rules require authority, either in the form of public government or private or community governance. This argument can be further developed, leading to the assumption that classic issues of politics – who governs? on what terms? who benefits? – are now as relevant as they were before the start of the ICT revolution. In one aspect, however, both prophets and critics of the ICT revolution are of the same opinion. The next century carries the potential of a new era for NGOs as opportunities will arise for new 'virtual communities' and networks that will provide a common platform for all non-governmental activities. The main reason is that by increasingly cheaper transmission of information, the number of players, mostly organised in loosely structured networks, will increase as well. Thus, the ICT revolution removed previously existing barriers to participation. These are effective in using local or regional constituencies in order to set the agenda of national leaders. Hereby, actors can penetrate states without regard to borders. The political effect of increased flows of free information through multiple channels seems to be clear: "*states have lost much of their control over information about their own societies. States that seek to develop (with the exception of some energy suppliers) need foreign capital and the technology and organisation that go with it*" (Keohane & Nye, 1998). Regional, local or even religious communities will still matter, but if a particular government wants to see rapid development it will find that many things have to be given up, mostly those which are perceived to be barriers to information flows. But what impact this will that have with regards to new and knowledge intensive and expertise dependent technologies? Do better communication technologies automatically mean better communication?

In regard to power, the history of human development has shown that knowledge has always been seen as power, or at least as a source of, and as means to gain, power. It provided the opportunity to be "*used for the good of many or the wealth of the few. So knowledge has always been sought, and if not found it is invented, or existing* *knowledge is altered and then called faith. Throughout history the proprietors of knowledge and the protectors of faith have fought to control and ration the dispersal of knowledge*" (MacDonald, 1999, p. 6). Both the political and the economic sphere have shown the same behaviour towards knowledge, and still do.

It needs to be reiterated that the state remains, either by blocking or encouraging technological innovation, the decisive factor in the overall process of change, as the state expresses and organises the social and cultural forces that dominate a given space and time. Furthermore, the level of a society's development itself is an important factor. This level can be measured by means of various indicators, for example the level of openness of a society, its ability to adapt to changes and the speed and comprehensiveness of which transformations take place. In addition, culture plays an important role, be it as a product of historical development and of tradition; as result of general political and societal conditions (internal environment of an cultural entity) or as a response to the external environment (impacts of neighbouring cultural entities). Since globalisation will even affect societies that do not want to take part in it, especially the latter point seems to be of increasing importance. The changing realm of politics will face many new challenges; two shall be mentioned here, as they are of major importance:

- intense growth rates of information and knowledge
- development of global networks for information and communication

The quantitative shift of content, the ratio and the density of information that will be sent around the globe might potentially lead to a shift within societies towards sectoral separation and social structure. Cultural predisposition, for instance, has the potential to lead to polarisation; Kahan *et al.* (2007, 2008) have investigated this phenomenon as part of a study of risk perceptions of nanotechnology (see Chapter 4.5). The typical slogan 'welfare for all' might soon be replaced by 'knowledge for all', or better still, the right knowledge for the right people (with the right interpretation).

2.4 Summary

This chapter has highlighted that not only the global playing field has changed, but also that technological change is transforming the economic, social and political spheres of modern societies. The new, so-called 'knowledge-based economies' are characterised by shrinking costs of global transactions, or, as Castells (1997) put it, by their informational mode and global focus. A popular indicator to measure the output of the knowledge-based economy is patents; and their number have skyrocketed (WIPO, 2007) over the past decades. Emerging technologies, such as biotechnology, genetic engineering, nanotechnology and Synthetic Biology will soon be the new ICTs.

What does all this mean for politics, for society and for ordinary citizens? First of all, as Keohane and Nye (1998) confirm, the state remains by either blocking or encouraging technological innovation the main player, and thus, the main organiser of change. Hence, politics will remain politics, and political power will continue to depend on harnessing economic prosperity. However, the current intense growth rates of information and knowledge will increasingly challenge those in power. This is also due to the rise of both global networks for information and communication and due to the rise in the number of players, be it globally or locally. Furthermore, the increasing amount of knowledge and information held by corporations will put further strains on the areas of politics, but also on societies.

As for the debate of information society vs. knowledge society, current trends indicate that modern Western societies steer towards the latter. Although the influence of computer-based networks and the ICTs in general on societies, as defining arguments used by Krohn (2001), is important, it pales in comparison to the importance of knowledge and its implications for society; dealing with uncertainty, insecurity and ambiguity. The key element defining this knowledge society is not that merely the amount of knowledge increases, but that large numbers of the citizenry and government will be challenged by this. The result is an increased need for expertise and one can argue that the new complexity and knowledge-intensity will lead to an expertise dependency.

3. Knowledge, expertise and policy making

As noted by Sabatier (1991), there is a need to find out more about the use of information in choice situations. Similarly, Oh and Rich (1996) argue that there is a need to better understand the role of data and information in policy-making. In particular, knowledge utilisation in the policy process still leaves much to be desired. In order to better understand the use of information and knowledge in the policy context, information, knowledge and its components require further investigation. Also, in policy contexts, the terms information and knowledge are often used generically, although substantial differences exist. These differences have implications for policy-making. For instance, when making policy choices, policy-makers require usable knowledge (Haas P. M., 2004). But what is usable knowledge, better still, what is knowledge, information, or data?

Information and knowledge play a very particular role in policy-making, that is, to enable participating actors to deal with uncertainty and to cope with complexity. There are, however, many different approaches that attempt to explain actors' behaviours towards both uncertainty and the use of information. Nonetheless, there is a lack of coherent theories that explain the policy process, thus available approaches or theories of the policy process have received much criticism. By looking at three of these theories, and in particular, by looking at how these differing approaches deal with uncertainty and the use of information and knowledge, this chapter aims to identify potential implications when dealing with nanotechnology. For this to work, a knowledge framework has been developed that looks at different types of knowledge, which will then be applied in the analysis (Chapter 6) section of this thesis.

3.1 Defining data, information, knowledge and expertise

3.1.1 Data

The Latin word *data* is the plural of *datum*. The related irregular verb is *dare* (also *dó, dedi, datum*), which means 'to give'. Thus, the term datum refers to a statement (a given or something given). Often, the terms 'given' and 'data' are used interchangeably, most notably in mathematics, geometry and engineering, paving the way for using the concept of data in computer science. In the English language, the word data is used as a singular mass noun. Albeit technically incorrect, data is commonly used to describe a set of data whereby it is referred to as if it were the singular datum. For instance, when someone says that 'this data is corrupt' instead of 'these data are corrupt' it is perfectly understood that the person does not refer to one particular datum that is corrupt, although Latin grammar rules allow for this meaning only when used in conjunction with a singular article. In computing, data are numbers, characters, words or images and as such represent mere statements of 'things that are given'. This data is often processed further by human-/computer- interaction, whereby the actual data processing can occur in various forms and stages.

Metadata is a description used to define data that contains 'information' (meaningful data) in their properties. In the area of information and library sciences, a library catalogue is often regarded as an example for metadata, as it not only lists other data but also gives it meaning (i.e. bookshelf number, number of available copies, *etc*.) Based on that description, metadata is to a certain extent not data, but already information and it provides the user (or computer programme) with instructions and interpretations.

It has often been highlighted that un-interpreted data has no meaning (MacDonald, 1999; Davenport & Prusak, 2000). This is not much of a surprise, since even the most simplistic observation has no meaning, without interpretation. Nonetheless, data itself is a key component of information and the act of adding meaning to data results in the production of information. This can be done by both humans and various forms of computing devices - be it independently or simultaneously - and requires one or more stages of interpretation and pre-processing and transfer of data. With regard to information and knowledge, data[11] has to be seen as a starting point. Data in their form as base units often consist of texts (in alpha- and/or numeric form) and pictures. Davenport and Prusak define data as "*a set of discrete, objective facts about events. In an organisational context, data is most usefully describes as structured records of transactions*" (Davenport & Prusak, 2000, p. 2). And in reference to Peter Drucker, who

[11] Throughout this thesis, data is used in its grammatically correct form, except when used in or as part of quotations, which have not been altered for the sake of clarity and originality. Data is the plural of *datum* (lat.), although it is commonly used in a singular case (i.e. data is…).

once said that "*information is 'data endowed with relevance and purpose*" Davenport and Prusak suggest that "*data by itself has little relevance or purpose*" (Davenport & Prusak, 2000, p. 2). Data only become information when they are structured and measured systematically. Nonetheless, data are most relevant to organisations as they are the "*raw material for the creation of information*" (Davenport & Prusak, 2000, p. 3), and henceforth the creation of knowledge.

3.1.2 Information

Terms such as information age, information society, information economy and information technologies have been over-used in recent years and have led to an careless use of the word 'information', whereby the narrower meaning of the term has often been used without careful consideration and without taking the various meanings of the term information into account (for a discussion on information society, economy and ICTs in general, see Chapter 2). Often, the word 'information' is used interchangeably with words such as news, advice, message, data and, of course, knowledge. Originally, the word information stems from the Latin word *informare*, which can be translated into 'to notify', 'to advise', 'to let someone know' or 'to tell'. Since the 15th Century, the word *to inform* slowly replaced local expressions and became part of the day-to-day vocabulary - to let someone know or to apprise someone of something became to inform (Lyre, 2002). Rowley argues that, at an intuitive level and based on life experience, one should know what information is, especially when one is aware of the importance of information, "*yet information remains an elusive and ill-defined concept and despite an ever expanding body of investigation on the various aspects of processing of information, there remains much to be understood about information processing at individual, organizational and societal levels*" (Rowley, 1998, p. 244). In order to determine some aspects of the various uses of the term information, Rowley starts out investigating basic dictionary entries of the term before looking into meaning and perception within various other disciplines, such as communication theory, library and information science, information systems and computer science, other professional disciplines, marketing, cognitive science, organisation science and policy-making. Lyre (2002) investigates the topic with regards to physics, biology and philosophy in detail.

In the end, Rowley's conclusion is that, although there is no single definition that could sufficiently define the term information fully, information must be regarded as context specific and suggests viewing this variety of uses and meanings as richness, rather than untidiness (Rowley, 1998). Nonetheless, for clarity and in the context of this research, the use of the term information shall be briefly described for one particular discipline, information theory, and from a very generic, but useful perspective with regards to policy-making, as policy information (see Chapter 3.5.3) is still an area requires much more research (Sabatier, 1991b).

Information theory, based on semiotics, approaches information from a triangular perspective and therefore takes syntax, semantics and pragmatics into account. Here, the syntax relates to the appearance of individual information units and their relation to each other while semantics relates to the meaning, and pragmatics to the effect of information. According to Lyre, all three aspects of information need to be looked at, if one wishes to avoid of having an incomplete view of information. Based on the works of Hartley (1928) and Nyquist (1924), Lyre connects the terms information and probability in order to come to the conclusion that both are equal terms to quantify possibility. As for the semantic and pragmatic aspect, based on Weizaecker (1971, 1985), Lyre employs two hypotheses: information is only what is understood and information is only what also generates information. The first describes the semantic and the second the pragmatic aspect. The problem here is that both arguments only work in conjunction with each other. Lyre provides an example: a person A asks a person B to switch the light off. Quite obviously, the light will only be switched off if the 'message' is first understood and then also put into practice. Information theory further considers additional meanings of the term information, mostly subject and/or context-specific (i.e. physics, biology) and always depending on the general framework or the setting, intentions and reference (Lyre, 2002).

From a very generic perspective, information can be described as a message, "*usually in form of a document or an audible or visible communication. And with any message, it has a sender and a receiver. Information is meant to change the way the receiver perceives something, …*" (Davenport & Prusak, 2000, p. 3). Without saying anything about the attributes that determines the character of a message, information can simply be a message communicated from a sender to a receiver, whereby both receiver and sender can be either a human or a machine (any type of technology capable of sending and/or receiving information). In addition, when speaking about information as a message, nothing has been said about the quality of the information, about its accuracy or worth. For instance, if the sender and the receiver do not employ the same decoding, translation or interpretation mechanisms, information as a message can also have negative, even disruptive, effects. In a similar vein, messages can deliberately be sent in order to disrupt flows of information or to create misunderstanding, no matter whether this relates to a technical field or the realms of politics or economics. Thus, information is organised to represent meaning. It consists of data that has value added to it. This can be done in various ways, most commonly however, when data has been contextualised, categorised, calculated, corrected and/or condensed (Davenport & Prusak, 2000).

In a politics context, Keohane and Nye (1998) highlight three different types of information that can be seen as sources of power:

> *Free information* is information that actors are willing to create and distribute without financial compensation. The sender benefits from the receiver believing the information and hence has incentives to produce it. Motives may vary. Scientific information is a public good, but persuasive messages, such as political ones, are more self-serving.
>
> *Commercial information* is information that people are willing to create and send at a price. Senders neither gain nor lose by others believing the information, apart from the compensation they receive.
>
> *Strategic information*, as old as espionage, confers great advantage on actors only if their competitors do not possess it. One enormous advantage the United States had in World War II was that, unbeknown to Tokyo, the United States had broken the Japanese codes. The quantity of such information is often not particularly important (Keohane & Nye, 1998).

Examples of free information, according to Keohane and Nye, are marketing, broadcasting, and propaganda. The sheer quantity of available free information "*is perhaps the most dramatic effect of the information revolution*" (Keohane & Nye, 1998). Yet, at the same time, the quality of free information can range from being accurate and exact to being misleading and completely false. This is also a risk that comes with free information, and it is up to the receiver to make a judgement. As for commercial information, Keohane and Nye argue that, for this information to be available (on the Internet, for example), "*issues of property rights must be resolved so that producers of information can be compensated by users*" (Keohane & Nye, 1998). Today, strategic information is, however, not limited any longer to the realm of espionage and politics, at least not in the classical sense, as increasing industrial espionage, copyright and patent infringements put both espionage and the use of strategic information on the agenda of the corporate world.

To conclude, the term information has many meanings and therefore always requires being treated as context-specific. The key element, however, is the fact that the sender and receiver need to use the same decoding mechanisms so that information is understood. The latter is also a main point when it comes to the use of information in a policy-context and with regards to political participation. Depending on the context, information is closely related to other concepts, such as communication, representation, knowledge and so forth.

3.1.3 Knowledge

Knowledge itself cannot be explained as clearly as data or information. Any attempt to explain knowledge has to start with some introductory remarks on humankind's search for knowledge, as this is probably as old as the human species itself. The majority of the literature starts off with historic roots dating back to Plato and/or Aristotle (Nonaka & Takeuchi, 1995; Davenport & Prusak, 2000), yet when looking at knowledge in form of either literature or historical accounts (i.e. Aesop's Fables, Herodotus -The Histories) or on early scientific achievements (i.e. Thales of Miletus) then one can argue that the early accounts on knowledge date back even further. Nonetheless, there is common agreement that both Plato and Aristotle were one of the firsts who attempted to both explain and classify knowledge. Since Western understanding of knowledge and knowledge-related terminology is deeply rooted in Ancient Greek writing and philosophy, some terms regularly used in the literature require further clarifications. The Greek word *epistèmè* means sciences, although it is often translated as knowledge. According to the OECD (2001) this knowledge is also regarded as being both universal and theoretical and as such equals 'know- why'. *Technè*, on the other hand, is Greek for craftsmanship or craft, and is often used to explain knowledge that is instrumental, context-specific and practice-related and as such equals 'know-how'. *Phronesis*, another term used by Aristotle in his *Nicomachean Ethics*, refers to knowledge that is normative, experience-based, context-specific and related to common sense and as such equals 'practical wisdom' (OECD, 2001). As opposed to both *epistèmè* and *technè*, *phronesis* contains a certain relativistic component that stresses on reflection in a person's life. When measuring between what has been set out to be achieved and what had been achieved, *phronesis* plays the part that has to do with setting realistic goals that are achievable. It is the practical wisdom that enables a person to act 'wisely' and thus be realistic in respect of the goals set in his/her life.

The Greek word *λόγος* or *logos* means word, although it is also often translated as knowledge. Heraclitus used *logos* to describe human knowledge, the knowledge that is inherent in the universe and the knowledge that helped to explain day-to-day life. Later, Socrates, Aristotle, and Plato used *logos* to describe human reason and the knowledge men had of the world and of each other. Deriving from that, Aristotle developed the concept of logic, the study of the rules that describe human rationality. Knowledge is the translation of the Greek word *γνώσις* or *gnosis*, although in practice it has several other uses. *Gnosis* is often described as intuitive knowledge of spiritual truths that ancient Gnostics were said to have possessed. Today, *gnosis* is often compared to esoteric or secret knowledge, and is often used in pseudo-science and amongst conspiracy theorists (often in conjunction with the alleged existence of ancient and secret orders) and receives a rather negative and doubtful connotation. The table below summarises the above-mentioned Greek terms according to their translation and usage:

Greek	Translation	Usage
epistèmè	Science	knowledge, know-why
technè	craftsmanship	know-how
phronesis	Wisdom	practical wisdom
logos	Word	human knowledge
gnosis	Knowledge	intuitive knowledge, secret knowledge

Table 1: Ancient Greek origins of knowledge

One has to recognise the literature (Sosa & Kim, 2001; Ziman, 1991) that examines the foundations of knowledge and attempts to determine the limits to human understanding. This literature is mostly of an epistemological nature, a branch of philosophy (Sosa & Kim, 2001; Dancy & Sosa, 2001). Epistemology itself is too large to be covered here. Nonetheless, and before going into more detail, some approaches to knowledge need to be introduced.

Apart from a scientific mode of generating knowledge, one can distinguish between the authoritarian mode, the mystical mode and the rationalistic mode. Frankfort-Nachmias and Nachmias point to the fact that "*[m]ajor distinctions among these modes lie in the way each vests credibility in the source or producer of knowledge (that is, Who says so?), the procedure by which knowledge is produced (How do you know?), and the effect of that knowledge (What difference does it make?)*" (Frankfort-Nachmias & Nachmias, 2002, p. 3). Most interesting here is the authoritarian mode, where "*people seek knowledge by referring to individuals who are socially or politically defined as qualified producers of knowledge*" (Frankfort-Nachmias & Nachmias, 2002, p. 3). For instance, this can refer to general knowledge creation in an authoritarian system, i.e. the former Communist states in Central and Eastern Europe, where the writings of Marx, Engels and Lenin have been regarded as being superior and hence of highest importance for the development of these countries. This authoritarian form of knowledge is also important to today's societies. For instance, when it comes to assessing risks of technology or products, society relies on authorities to make the appropriate decisions that, in turn, protect society as a whole and its individuals from harm. This is, to a certain extent, execution of knowledge authority. With regard to the former Communist states, the relevance of this observation in both a business and a political context becomes clear by looking at the state of their economies at end of the 1980s. The authoritarian mode is also in the democratic western world of interest, as it places 'socially qualified producers of knowledge' in a position that has wide-ranged implications. Here, one needs only to look at the distribution of information that influences the stock market, or, at institutions that impact day-to-day business practices. In addition, it can also refer to the interpretation of scientific data and information by a reputable expert (where, at the same time, nothing has been said as to how the expert became reputable, or who made him/her reputable, nor about who determined that this person is an expert at all). Thus, exercising knowledge authority can be used for the good of all, or to the advantage of a few, no matter whether these are governments, corporations or individuals. Summarising, one can say that while undertaking any research that relates to the subject matter, one has to be aware of approaches to knowledge creation and its implications. It, however, also illustrates that defining knowledge is not a simple task. This is supported by the fact that, for instance, a number of scholars, both within the area of epistemology and outside, define knowledge differently. Moreover, the sheer historicity (for instance, knowledge both a concept and as a subject of study) allows for various approaches to exist simultaneously, which, in addition, often use the same terminology and sometimes even the same methodology.

Nonetheless, Davenport and Prusak offer a 'working definition', that relates to the definitions they have offered for data and information. The authors suggest that "[k]*nowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practices, and norms*" (Davenport & Prusak, 2000, p. 5). Since it has been established that knowledge derives from information and information from data, one now has to look into what is required to transform information into knowledge. Although this is surely not fully comprehensive, Davenport and Prusak suggest that this transformation happens through:

- Comparison: how does information about this situation compare to other situations we have known?
- Consequences: what implications does the information have for decisions and actions?
- Connections: how does this bit of knowledge relate to others?
- Conversation: what do other people think about this information? (Davenport & Prusak, 2000, p. 6).

Most importantly, however, it has to be noted that the transformation of information into knowledge happens through human (inter-) action. Knowledge can only be obtained from people, whereby data can be found in records and information can be gathered from messages (Davenport & Prusak, 2000, p. 6). In addition to the above, there are some other aspects that need to be looked at. For instance, and apart from knowledge creation, there are things such as knowledge absorption (i.e. though learning), experience (i.e. indirect learning and constant re-evaluation of the learned), intuition (the feeling for what is right), judgement (i.e. decisions based on previous experience and on what has been learned), beliefs and values (i.e. ethical decisions of what is right). These aspects of knowledge are especially relevant in politics and policy context. For instance, Sabatier (1988) stresses the importance of both beliefs and learning as part of his advocacy coalition framework (see Chapter. 3.5.2). Moreover, in a practical context, two forms of knowledge can be mostly differentiated: tacit and explicit knowledge. In general, one can argue that explicit knowledge is precise, clear and expressed in such manner. Tacit knowledge on the other hand, is usually not always clear, as it is very often personal knowledge, based on individual experience and influenced by personal beliefs, perspectives and values (MacDonald, 1999; for a detailed discussion on tacit knowledge, see 3.3.1).

Within philosophy, knowledge is also often described as a form of awareness that has either been obtained *a posteriori* by means of observation (i.e. through interaction, experience and learning) or *a priori* (i.e. through introspection, but without observation) (Dancy & Sosa, 2001) and is defined as justified true belief, a conditional statement that attempts to set out under which circumstances given statements can be accepted as true (Sosa & Kim, 2001). *A posteriori* knowledge is also called empirical knowledge. Another distinction often made is inferential knowledge vs. factual knowledge, whereby the former relies upon reasoning from facts or theory and, as such, it can either be verified or not through tests or observations. Factual knowledge, however, is based on direct observation (Williams, 2001). In either case, nothing can be said upfront as to whether the obtained knowledge can be regarded as certain, since errors can always be made throughout the observation, test and interpretation phases.

On a very practical level, knowledge also needs to be verified. This, depending of the type of knowledge and the subject matter that needs to be verified, can be executed by various means. A person who buys a product can most likely verify its quality, depending, of course, on the type of product and the buyer's knowledge about it. Verifying the quality of a service on the other hand is already more difficult, as this might require a certain familiarity with the service and/or a given level of similarity to other known services (The World Bank, 1999). Verifying more complicated forms of knowledge requires knowledge in itself; an employer who wants to hire a specialist, a prospective student who wishes to choose the right subject and right institution for him/herself, or legislation brought in to the parliament about regulating new technology are only a few examples. For instance:

> In medieval Europe and in the Arab world until the late 19th century, guilds provided quality control, inspecting inputs and production processes and punishing dishonesty. Amins, the heads of local craft guilds in major cities throughout the Middle East and North Africa, were knowledgeable, respected individuals to whom consumers could turn to test sellers' claims about the authenticity and quality of their goods (The World Bank, 1999, p. 73).[12]

Today, who verifies that a policy-maker has adequate knowledge? And who verifies that Members of Parliament are skilled and knowledgeable enough to make complex

[12] These rather individually held positions have now often been replaced by publicly acknowledged institutions, especially in the West.

decisions? What is more, even if these people are knowledgeable, who can guarantee that they possess the 'right' knowledge?

Before finishing this section about knowledge, it needs to be pointed out that the approach and concepts of knowledge, as used in this thesis, excludes discussions about scepticism and its core questions, such as: Is knowledge possible? The unique identifier pertaining to knowledge, as discussed here, is the application of it in practice or in practical contexts, independently of philosophical justifications. Hence, all of the concepts described in this thesis assume that knowledge is possible. However, it should also be made explicit that there are many more possibilities to both approaching concepts of knowledge and to providing taxonomies/classifications for knowledge. Over time, knowledge as a subject matter and area of research and interest has evolved and the overall body of knowledge surrounding the topic has grown immensely. Philosophy and Sociology are the obvious areas that study knowledge, but even within these disciplines, the numbers of sub-disciplines dedicated to the subject in question have sky-rocketed over time. The larger implications of this trend are not known yet. However, in order to shed some light onto a number of the aforementioned questions, a look at different knowledge types with relevance to a practical context is required.

3.1.4 Practical aspects of knowledge

As an approach to knowledge in practice, the classification of Lundvall and Johnson (1994, quoted in OECD, 2001, p. 14) can be employed. The authors argue that knowledge can also be classified as:

- Know- what
- Know- why
- Know- how
- Know- who

In comparison, this concept seems to be close to aforementioned knowledge taxonomy of Aristotle, who distinguished between:

- *Epistèmè*: knowledge that is universal and theoretical: "know- why."

- *Technè*: knowledge that is instrumental, context- specific and practice- related: "know- how."
- *Phronesis*: Knowledge that is normative, experience- based, context- specific and related to common sense: "practical wisdom." (OECD, 2001, p. 15).

The first point in Lundvall and Johnson’s classification - 'know-what' - refers to factual knowledge, which can be expressed by answering simple questions that have fact-based answers: “*How many people live in New York, what the ingredients in pancakes are, and when the battle of Waterloo took place are examples of this kind of knowledge*” (OECD, 2001, p. 14). It is argued that knowledge that pertains to this group is due to its simplicity “*close to what is normally called information*” (OECD, 2001, p. 15). The decisive element is that this type of knowledge can be separated or broken down into its parts and then communicated as data.

The second point, 'know-why' “*refers to knowledge about principles and laws of motion in nature, in the human mind and in society*” (OECD, 2001, p. 15). This knowledge is required to understand and further develop technological progress; thus it is the fundamental knowledge behind science that explains, for instance, processes in chemistry, physics, material sciences and so on. But it is also the knowledge that explains social scientific or historic phenomena, such as the Industrial Revolution, or it is used to answer questions such as why the First World War broke out. From both an economic and technological perspective (and, of course, from the perspective of power politics) access to this knowledge enables the user to make advances in his/her research area more rapidly and reduces also “*the frequency of errors in procedures involving trial and error*” (OECD, 2001, p. 15).

The third point, 'know-how' can be related to skills and the ability to do something, which includes the skills of a manual worker to do his/her job or that of an analyst to observe the stock market in order to give advice to investors. In general, one can argue that this knowledge plays a key role in all societal and also economic activities. 'Know-how' is, however, more than just practical knowledge, and it would also be wrong to characterise it as “*practical rather than theoretical. One of the most interesting and profound analyses of the role and formation of know-how is actually about scientists’* *need for skill formation and personal knowledge* (Polanyi, 1958/1978)" (OECD, 2001, p. 15). This has profound impacts on the use of expertise, for instance, when expertise is used in court cases as expert witness statements (Page & Lopatka, 2004) or in a policy context. Another example is that given by Ziman (1997) who suggests that "*finding the solution to complex mathematical problems is based on intuition and on skills related to pattern recognition which are rooted in experience- based learning rather than on the mechanical carrying out of a series of distinct logical operations*" (OECD, 2001, p. 15). Due to these characteristics, 'know-how' is usually kept within individual organisations or research teams and, only when the complexity of the subject matter increases, is it shared between organisations and teams. A result of this sharing is networking, which, in turn, points to the importance of the last of Lundvall and Johnson's classification points: 'know-who'. In the context of policy-making, for instance, the importance of know-who is illustrated during coalition building processes, where participating actors of coalitions form around core beliefs. 'Know-who' impacts the composition of such coalitions (Sabatier, 1988).

The fourth and last point, 'know-who' refers to knowledge (and information) about "*who knows what and who knows what to do. But it also involves the social ability to co- operate and communicate with different kinds of people and experts*" (OECD, 2001, p. 15). As knowledge in general becomes more and more complex, it often requires more than one person to perform a particular challenging task or to solve a difficult technical issue. Or as Pavitt (1998) puts is: "*The general trend towards a more composite knowledge base, with new products typically combining many technologies, each of which is rooted in several different scientific disciplines, makes access to many different sources of knowledge more essential*" (OECD, 2001, p. 15). But 'know-who' also applies to personal knowledge (Who knows where to buy the cheapest airline tickets?), and is therefore not exclusive to the technical or academic world. To summarise, practical aspects of knowledge must be understood in order to deal with complexity that either impacts society or the individual.

3.1.5 Expertise

Expertise can broadly be defined as a process of illustrating outstanding performance by a person. In general, expertise is most likely, although not necessarily, limited to a certain domain or subject matter. Depending on the holders of that expertise, it can, however, also span over more than one domain, especially if they are closely related. Gruber describes experts, as follows:

> Experts thus are persons who, by objective standard and over time, consistently show superior performance in typical activities of a domain. Expert performance in often illuminated by comparison with individuals with limited performance. Such individuals are called 'novices'. In contrast to giftedness, expertise is usually considered as acquired special skill in or knowledge of a particular subject through practical experience (Gruber, 2001, p. 5146).

Experts in virtually any complex domain have intensively practiced for 10 years or more (also regarded as the 10-year rule of necessary preparation), and thus have extensive knowledge at their disposal (Gruber, 2001, p. 5146). Although this 10-year rule is a 'rule of thumb' measure, it has to be acknowledged that even very gifted and talented individuals require such a period of time, or a period of time that comes close to this, which is mostly spent with preparation, learning, and practical acquisition of knowledge through repetition. Gruber argued that most experts require much longer periods of time. Therefore, expertise depends not only on the holder's ability to memorise and to accumulate knowledge; it also depends on more abstract skills such as perception and problem-solving skills. In addition, the acquisition of expertise is contingent upon the subject matter or context to which expert knowledge relates and is thus not easily comparable in a like-for-like fashion. For instance, acquired expertise in nanotechnology cannot be easily compared with or related to acquired expertise in political or corporate decision-making, as expertise is always domain-specific and thus the acquired skill sets of the expertise holders may vary considerably. As a result of this domain specificity, expert knowledge cannot be simply transferred, although as mentioned before, expertise may span over more than one domain. With time, an expert may be able to expand his expert knowledge beyond his original domain. For instance, a business analysis expert may over time also develop expert knowledge of systems analysis, if that is his/her (additional) domain of work.

Although the domain specificity suggests that working with, and the analysis of, domain-specific knowledge plays a key role; expert knowledge must not be equated with domain knowledge. Declarative domain knowledge is also often associated with *know-what* and as such to be distinguished from proceduralised knowledge, also called *know-how*. The latter one is a key component of the process of acquiring expertise. Gruber (2001) argues that with growing expertise, proceduralisation moves into the forefront. According to Anderson (1982), skill acquisition can be categorised into three phases:

- the declarative phase,
- the compilation phase and
- the tuning phase,

which can be summarised as follows: declarative knowledge is acquired, which is compiled (or better said, becomes proceduralised) through action sequences and is then finally tuned by means of repetition.

Other distinctions of expertise can be found in Hatano and Inagaki (1986) and in Patel and Groen (1991). Based on research into child development, Hatano and Inagaki make the distinction between adaptive and routine expertise, with the first relating to the fact that a repeated application of a "*procedure with variations is very likely to lead to adaptive expertise*" (Hatano & Inagaki, 1986, p. 33) whereby the latter, routine expertise, *"may in fact produce more or less "generalized consequences", not through understanding but through well established patterns and/or modes of processing*" (Hatano & Inagaki, 1986, p. 32). The latter points to the complexity that is inherent in acquired expertise. Often, the owner of this type of expertise is not aware of possessing it. This has implications for accessing this type of expertise, especially when this expertise is to be accessed outside the expertise holders' environment. Patel and Groen, on the other hand, have carried out research into the medical professions and distinguish between generic and specific expertise. According to Patel and Groen, specific expertise is based on sufficiently available generic expertise and the development process from generic to specific expertise can be summarised as follows:

- beginners have declarative knowledge available;
- intermediates have already compiled their knowledge into simple procedures;
- generic experts dispose of domain-specific schemata and scripts;
- specific experts have enriched these with case experience.

The latter is a point of interest, as increasing knowledge-intensity calls for specific expertise. Nonetheless, and no matter as to whether aspired expertise is to be either generic or specific, practicing within one or more domains is considered to be a necessary component, if not condition, in the process of acquiring expertise. According to Ericsson *et al.* (1993) and Ericsson (2000), training activities need to aim to purposefully improve performance, a process called deliberate practice. This, however, needs to be distinguished from 'normal' practice and training activities as its aim is not to acquire more declarative knowledge but to improve the quality of expertise. This is often done by experts designing their own training curricula and by monitoring their own performance. Finally, it needs to be noted that there is no all-encompassing expertise. Expertise it is always problem-specific and comes with infinite variations, depending solely on the issue at hand. This has implications to those who wish to employ expertise. Political arguments are often centred on varying points of view and the number of disagreements potentially increases with the number of players involved. Furthermore, the domain-specificity of expertise limits its use even when it comes to closely related domains. An example, which will be discussed later in this thesis, is that of expertise in nanotechnology vs. expertise in the impacts (health, environment) of nanotechnology (see Chapters 4 and 5).

3.2 Knowledge by acquaintance/description

The concept of differentiating knowledge by its form of acquisition is mostly linked to Bertrand Russell, though John Grote first introduced this distinction. By referring to the natural language, Grote argued that there is a distinction between "*two applications of the notion of knowledge, the one being γνώναι, noscere, kennen, connaître, the other* *being εἰδέναι, scire, wissen, savoir*" (Grote 1865, p. 60, quoted in Martens 2001, p. 237). Whereby the English language does not distinguish between different forms of 'to know', Greek, Latin, German, French and other languages do so. The Ancient Greek *γνώναι* or the French *connaître* can be translated into English as 'know; be aware of; understand; and experience' (Langenscheidt, 2000), and the translation of the German *kennen* is 'know and/or be acquainted with' (Langenscheidt, 2000). Grote's second notion of knowledge, *εἰδέναι* or *savoir* can be translated as 'know; be aware of; know how to; be able to and learn' (Langenscheidt, 2000). Although none of the translations are 100 % clear, by comparing one or more translations for the two different words, one can identify similarities in other languages leading to the following.

The first notion *γνώναι* (*noscere, kennen, connaître)* refers to knowledge by description[13], and the latter notion *εἰδέναι* (*scire, wissen, savoir*) refers to knowledge by acquaintance[14]. Helmholtz compared knowledge by description to the "*mere familiarity with phenomena*" (Helmholtz 1962, 269-75, quoted in Martens 2001, p. 237), in other words it refers to knowledge **about** things. Knowledge by acquaintance, on the other hand, refers to things one is acquainted with, or one has learned. There are two forms of distinctions between the two notions that seem worthwhile exploring. The first refers to the value of knowledge, both in theoretical and practical terms. The other distinction refers to its application in practice. Martens points out that Russell, Grote and James agreed that:

> First, knowing things involves experiencing them. Second, knowledge of things by acquaintance is epistemically basic and provides an infallible epistemic foundation for knowledge about things. … Third, knowledge about things is more articulate and explicit than knowledge by acquaintance with things. Fourth, knowledge about things is casually removed from knowledge of things by acquaintance, by processes of reflection, analysis and inference (1911, 1913, 1959) (Martens 2001, p. 239).

[13] See also the translation of the French as 'be aware of', of the German 'be acquainted with' (as opposed to knowledge by acquaintance).
[14] See also the translation of the French as 'know how to' and 'be able to'

This means first and foremost, that **knowing** (things) refers to a practical encounter with something and that it is direct. In the narrower sense of the word, it is henceforth knowledge by acquaintance. Therefore, **knowing** (things) include forms of 'knowing about (things)'[15], whereby 'knowing about' does not automatically include knowing. Deriving from that, one can argue that knowledge by acquaintance receives a higher value; it is regarded as epistemically prior to knowledge by description. This is further supported by the above argument of Russell, Grote and James that knowledge about things is regarded as being more articulate and explicit.[16] A practical example might shed a bit more light on this:

A person that learns (1) how to operate and to use (2) a computer application, such as a word processor or a spreadsheet programme, has acquired (result of 1) knowledge (result of 2) by acquaintance. A person that simply knows about the same computer applications is not automatically able to use them. Hence, this knowledge about can also be described as 'having heard of, or having heard about', whereby nothing is said or for sure about a person's ability.

Further in respect to the value of knowledge, James argued that "*these mere matters-of-acquaintance, are the only realities we ever directly know*" (James 2002, p. 35), which leads to the conclusion that knowledge by description is both indirect and far less valuable regarding its relation to direct practical application. The importance of this shall be illustrated in another practical example. In an interview situation, the following dialogue develops:

> Q: What do you know about spreadsheet applications, such as Microsoft Excel?
> A: Quite a lot, MS Excel is a very powerful tool.
> Q: How much do you know about the use of logical functions?
> A: We (the current employer) use them to establish whether certain conditions are met, for instance, whether all fields in our database have been populated.

[15] Or 'knowledge by description', as Russell preferred to speak of (Martens 2001, p. 240).
[16] See also the discussion about tacit and explicit knowledge.

The above example is not too far away from reality. Supposedly, the interviewee has been hired without further testing or verifying of his/her abilities, the company might now face the risk by *de facto* not knowing about the person's ability to use spreadsheet applications. At first sight, especially the second answer looks very impressive, but it does not contain any information as to whether the interviewee is able to use this or any other type of logical functions. He/she might simply be aware that those types of functions are used in his/her current environment. Furthermore, the interviewee even might have been very honest by stating the above, the reference as to whether he/she is able to perform might have been simply omitted, as this question has not been asked specifically. The same type of interview could potentially be carried out with a politician or an industry representative, but this time focussing on nanotechnology:

> Q: What do you know about nanotechnology and its applications, such as the use of nanosilver?
>
> A: Quite a few things actually. Nanoscale silver is used by leading manufacturers, such as Samsung, in their washing machines.
>
> Q: How much do you know about the properties of nanosilver?
>
> A: It has been proven in various studies that nanoscale silver has antibacterial properties; it can limit, if not prevent, bacterial infections. It is being used in bandages, antiseptic wound dressing and considerable success has been made especially when treating burn wounds.

These intentionally oversimplified examples, however, illustrate at a very simple level the complexity that pertains to the practical aspect of knowledge by description/acquaintance and the danger that comes with it, when one is not aware of its different forms and their implications. Here, the value of direct knowledge receives importance from a very practical point of view when, as shown in the examples above, an employer needs a person that is able to perform a certain set of tasks or a layperson may want to learn about nanotechnology.

However, there is also an importance to indirect knowledge; that is, the knowledge about things or simply put, knowledge by description. Following Skorupski's example[17] used in his foreword to Russell's 'The Problems of Philosophy', one can say: I know Berlin, which the capital of Germany. I also know that Moscow is the capital of Russia. The reason why I can say that 'I know Berlin' is because I have been there, "*not asleep, but conscious of my environment*" (Skorupski 1998, p. xii, in Russell 1998). My knowing of Berlin is, so to say, knowledge by acquaintance. Although I have never been to Moscow, I still know that it is the capital of Russia, that is, I know that Moscow, and no other city, satisfies the conditions being 'capital of Russia'. The importance of indirect knowledge is self-explanatory, most notably, however, in relation to one's ability to learn things without experiencing them. Again in practical terms, the danger is when one fails to update this knowledge by description when it becomes outdated. For instance, by saying that Moscow is the capital of the Soviet Union one satisfies the criteria that determine which city is the capital of the Soviet Union. In practice, this knowledge became obsolete, as the Soviet Union ceased to exist and Moscow now satisfies the conditions for being the capital of a different state. A further danger is when knowledge by description is used as a substitute for knowledge by acquaintance, as, for instance, in the aforementioned example of nanotechnology. If, for instance, a layperson does not consciously make a distinction between those two forms of knowledge, then actual knowledge by description may be confused with factual, expert knowledge. This is the more the case, as the originator of this knowledge is seen as an authoritative figure. As a layperson normally does not make a conscious distinction between knowledge by description and knowledge by acquaintance as well as authoritative forms of knowledge, assumptions held by the public about what is expert knowledge are often wrong.

In summary, one can say that both forms of knowledge have significant practical implication, albeit very different ones. The direct form, that is knowledge by acquaintance, plays an important role when it comes to the use of abilities that draw upon experience and personal familiarity with things. Indirect knowledge, that is

[17] Skorupski used the examples of Paris, where he has been, and Brasilia.

knowledge about things, comes into play when personal familiarity is not required, be it to either establish facts as truth (i.e. verification as to whether certain conditions are met) or to use this knowledge about things as commonplace in day-to-day life. The danger is that both forms are used interchangeably, or worse, that, when linked to authoritarian modes of knowledge, knowledge by description is confused with expert knowledge The concept of knowledge by description/by acquaintance, for instance, can be utilised by philosophers/epistemologists – who have a particular stance on it, but it can also be utilised by social scientists/practitioners who, in turn, approach the concept from a very different, one might say 'hands-on' perspective. Furthermore, the distinction of knowledge by their forms of acquisition has implications to the analysis of knowledge in regard to its practical use, and especially in regard to policy-making.

3.3 Tacit vs. Explicit

As already established, it seems quite impossible to find a commonly agreed and accepted definition of knowledge; surprisingly the same has to be said about tacit knowledge. It is surprising because, unlike the concept of knowledge, tacit knowledge has one generally accepted point of origin: the accounts of M. Polanyi.

3.3.1 Tacit knowledge

3.3.1.1 Defining tacit knowledge

Generally speaking, tacit knowledge is the knowledge that resides in people's heads; it is hidden, not easily accessible and its value becomes apparent when transferred into explicit, and thus easily accessible, knowledge (MacDonald, 1999). It also consists of directly unrecognisable habits, values, beliefs and cultural and behavioural attitudes in individuals and is, in addition to that, also inherent in group and organisational relationships. The fact that tacit knowledge is not directly recognisable makes it very difficult first to locate and to identify, and then to properly document (MacDonald, 1999). One of the main reasons for these difficulties is that the holder of the tacit knowledge in question may not even be aware of its existence and, in addition, may not have the necessary skills to articulate, map or describe this knowledge consciously. Often, the only way of both passing this knowledge on and to acquire it is within a master-apprentice-like training environment by means of observation and direct hands-on repetition and personal experience. As such, it can be viewed as the 'not articulable skill' or the ability to perform, analyse, infer, conclude and so forth.

M. Polanyi's examples include the ability or skill to swim or to ride a bicycle (more on these examples later), neither of which can be learned by reading a book about it or through listening to a lecture, but only by direct and personal experience based on observation and instruction by someone who is experienced. To give another example, M. Polanyi pointed out that although, "*[b]oth quantum mechanics and relativity are very difficult to understand; it takes only a few minutes to memorize the facts accounted for by relativity, but years of study may not suffice to master the theory and see these facts in its context*" (Polanyi M. , 2000, p. 16). In other words, anyone can memorise the simple formula put out by Einstein and yet most people actually have no comprehension of what $e=mc^2$ means. Another example of common tacit knowledge is provided by Sveiby. By referring to the Polanyian concept of tacit knowledge, he suggests that "*[w]hen we are tacitly involved in a process-of-knowing we act without distance. This describes how and why we take things "for granted"*" (Sveiby 1997).

For MacDonald, "*[t]he most valuable asset of every organisation is the hidden or tacit knowledge buried in the memories of employees and other people in regular contact with the organisation*" (MacDonald, 1999, p. 12). This tacit knowledge is the experience, which includes everything that has been learned from doing, studying and from observation. MacDonald even considers knowledge sources or means of distribution, such as gossip, as a relevant part of tacit knowledge. The definition above hints already that tacit knowledge is "*difficult to both recognise and collect let alone codify, store and distribute*" (MacDonald, 1999, p. 12). For Tiessen, Andiessen and Deprez, tacit knowledge is mainly characterised by its strategic focus and importance for an organisation, by its occurrence in a highly dynamic environment and by its complexity and highly unstructured nature. Without giving an actual definition, they argue that "*[t]acit knowledge usually focuses on strategic issues, helping companies to stay ahead of the game*" (Tiessen, Andiessen & Deprez, 2000, p. 187). Albeit this being a snippet of typical management jargon, it hints to the hidden character of tacit knowledge; the knowledge that some have and others do not, as it cannot be simply accessed and distributed.

Although it is generally accepted that the concept and notion of tacit knowledge has been introduced by M. Polanyi (2000), Barbiero (2004), by referring to Reber, points out "*that the idea that certain cognitive processes and/or behaviors are undergirded by operations inaccessible to consciousness … goes back at least as far as Helmholtz's work in the 19th century"* (Reber, 1995, p. 15 quoted in Barbiero, 2004). This reference to Helmholtz points to the concept of knowledge by acquaintance.

Undoubtedly, there seem to be a variety of forms of tacit knowledge that easily intermingle and merge with, or are at least very similar to, other concepts and forms of knowledge. It is therefore no surprise that tacit knowledge is often compared to know-how and explicit knowledge to know-that. Barbiero (2004) adds another comparison: that of embodied knowledge and theoretical knowledge. On this account, knowing-how or embodied knowledge is characteristic of the expert, who acts, makes judgements, and so forth without explicitly reflecting on the principles or rules involved. It is therefore also characteristic of knowledge by acquaintance. The expert works without having a theory of his or her work; he or she just performs skilfully without deliberation or focused attention. Knowing-that, by contrast, involves consciously accessible knowledge that can be articulated and is characteristic of the person learning a skill through explicit instruction, recitation of rules, attention to his or her movements, etc. (Barbiero 2004). Knowing-that, at least up to the point of consciously accessing knowledge, can be both knowledge by acquaintance or knowledge by description, as nothing has been said about the method of obtaining this knowledge. By developing his argument further, Barbiero (2004) suggests that know-that is a requirement at least throughout the skills acquisition phase, but as soon as the apprentice practices the acquired skills and therewith slowly develops his/her own know-how, know-that is no longer a necessity for the practice of these acquired skills. The 'not-articulable' know-how that has been acquired through observation, training and practice now resides in the former apprentice, but remains 'not-articulable', albeit being regularly used and applied. At this point, it has also become knowledge by acquaintance.

Nonetheless, the equation of tacit knowledge being know-how and explicit knowledge being know-that fails strict scrutiny once it is put to the test outside the field of simple craftsmanship. This becomes apparent when venturing into more complex areas that require skills far beyond that of simple technical or practised and applied know-how. The point here is that the ability to perform a certain task cannot always be attributed to tacit knowledge, especially not if that task is merely one step or part in a group of numerous and subsequent tasks and, despite being similar to the acquisition of know-how in craftsmanship, is based on motor skills combined with sufficient theoretical knowledge that, in turn, may require personal reflection or inference. Thus, in complex environments, tacit knowledge cannot be limited to know-how alone but also includes know-that. This is especially true when expert performance comes into play that indeed requires a minimum of sound theoretical understanding combined with intensive hands-on learning experience. In policy-making, for instance, where expertise dependency exists, tacit knowledge cannot be used by participating actors that come from the areas such as politics, bureaucracy and other public bodies whose primary task is governance. Moe (1995 provides an example about what happens when a dominant political group leaves technical expertise solely to externally sourced experts (see Chapters 3.5.2 and 6.4). Another significance that is attributed to tacit knowledge is that the person to whom one credits the possession of certain tacit knowledge has often no awareness of that knowledge, at least not consciously. Often, this tacit knowledge is only acknowledged by the person who possesses it after it has at least been attempted to make that tacit knowledge accessible in one form or the other.

3.3.1.2 Dimensions of tacit knowledge

Gourlay (2002, 2004) has undertaken an intensive study to track and to investigate the various meanings that are attributed to tacit knowledge. Depending on the discipline or area/field of study, perceptions and definitions of tacit knowledge differ. The phrase ‘tacit knowledge’ is nowadays not only used within the realm of philosophy, sociology and social sciences, but increasingly expands into business and management studies, psychology and cognitive sciences, artificial intelligence (AI) and ICT.

Nonaka & Takeuchi (1995) introduced the concept of tacit knowledge into the area of management studies in general, and into the field of knowledge management in particular. Gourlay argues that Nonaka & Takeuchi depart from M. Polanyi's perception of tacit knowledge as "*they distinguished between technical tacit knowledge meaning skills or concrete 'know-how', and cognitive tacit knowledge which refers to ingrained schema, beliefs and mental models that are taken for granted"* (Gourlay, 2002, p. 2). Similar to the know-how and know-that model, Nonaka & Takeuchi hold that tacit knowledge has two dimensions: a technical dimension based on craftsmanship and personal (technical) skills that develop and expand with experience; and the cognitive dimension based on mental models, beliefs and perceptions (Nonaka & Takeuchi 1995, p. 8). In addition, Nonaka & Takeuchi believe that tacit knowledge can be acquired through a process which they call 'internalization'. It suggests that tacit knowledge can be gained by experiencing the "*experiences of others*" (Nonaka & Takeuchi, 1995, p. 69). This is done by using documents, manuals, oral stories and other knowledge that has been verbalised or diagrammed (see also explicit knowledge).

Further, according to Gourlay (2002), various studies suggest that there are two dimensions of tacit knowledge: the personal dimension as introduced by M. Polanyi and a group or organisational dimension. As for the latter one, Aadne *et al.* (1996) suggest that tacit knowledge can also be found in organisational settings, such as a company as a whole, a department, a team or a collective. Similarly, von Krogh (1996) holds that tacit knowledge can be found in relationships. In the same vein, Baumard (1999) also identifies tacit knowledge as something that can reside in both individuals and in groups. Within organisational settings, however, Baumard distinguishes between implicit knowledge and tacit knowledge. Implicit knowledge is the knowledge that the person who holds it does not wish to share, whereby tacit knowledge is the knowledge that cannot be expressed as it is personal and often non-communicable

(Baumard 1999).[18] Choo (1998) also acknowledges the existence of the two types of tacit knowledge. On the one hand, there is the Polanyian type that is limited to individuals, and on the other hand there is tacit knowledge that can be attributed to groups. The latter one relates to shared practices and understanding amongst group members that work together. This can also be described as the so-called team dynamic that suggests that individual members often 'understand each other blindly'. Another group of studies has been carried in the area of psychology. Wagner & Sternberg (1985), for instance, define "*tacit knowledge as knowledge that is tacit in the dictionary sense of 'tacit'*" (Gourlay 2002, p. 7), which in plain English means 'silent' or 'not spoken'.

In his second study on the use of the concept of tacit knowledge, Gourlay (2004) has again identified two major groups that either accredits tacit knowledge to only the personal dimension or to both the personal and/or organisational dimension. Studies by Colis (1996), Johannessen *et al.* (2001), Nelson & Winter (1982), Leonard & Sensiper (1998), and Stenmark (2000-01) seem to support Gourley's argument. The organisational dimension is commonly expressed by organisational capabilities, routines, and procedures (or procedural abilities and knowledge).

Tacit knowledge acquisition always depends on the direct experience of an individual and builds on the personal contact of the learner and on his/her ability to learn through observation. Applying this to Choo's team model means that the direct experience of an individual becomes a direct experience of an entire group that builds on the personal interaction of each group member. At the same time, however, this could also mean that when a group or team performs a task together, that an individual team member possesses tacit knowledge only of parts of this common task; that is, for the task for which they have responsibility. This may particularly hold true when the task is of either enormous complexity or size and thus consists of numerous steps or sub-tasks. In addition, this may also be intentional. For instance, if work is carried out that is of a sensitive or secretive nature, then by means of design it can be

[18] In this respect, implicit knowledge may play an important role when it comes to scientific discoveries leading to patents and copyrights. It can be argued, that an organisation does not want to share its implicit understanding of things in order to deter both industrial espionage and competitors.

achieved that the overall 'whole picture' remains elusive to some or all team members. This included 'classic' notions, such as 'need to know' in intelligence or military operations as well as purposefully designed compartmentalisations in competitive corporate environments, especially when assumed to be the target of industrial espionage.

As for interpreting M. Polanyi, various accounts that have been published claim that M. Polanyi might have been misinterpreted. For instance, Tsoukas (2003) argues that M. Polanyi's tacit knowledge should be viewed as 'ineffable knowledge', whereby Gourlay (2002, 2004; also Sveiby 1997) points out that M. Polanyi was mainly concerned with the process of tacit knowing and not with a thing by the name of tacit knowledge: "*Knowledge is an activity which would better be described as a process of knowing*" (Polanyi M., 1969, 132 quoted in Gourlay 2002, p. 8). In addition, Gourlay suggests that when looking especially at tacit knowledge in organisations, M. Polanyi's concept may not be "*particularly relevant for understanding tacit knowledge in organizations*" (Gourlay 2004, p. 47). This also becomes apparent when looking at M. Polanyi's understanding of knowing, which is that of "*an active comprehension of the things known, an action that requires skill. Skilful knowing and doing is performed by subordinating a set of particulars, as clues or tools, to the shaping of a skilful achievement, whether practical or theoretical*" (Polanyi M. , 2000, p. vii). Furthermore, M. Polanyi's intention with his account on 'Personal Knowledge' was not to describe tacit and/or personal knowledge (or knowing) *per se*, but also to illustrate that complete objectivity is not just a delusion but actually a false ideal:

> But I shall not try to repudiate strict objectivity as an ideal without offering a substitute, which I believe to be more worthy of intelligent allegiance: this I have called 'personal knowledge (Polanyi M. , 2000, p. 16).

3.3.1.3 Forms of tacit knowledge

By referring to empirical research carried out by Collins (1974) and Wagner & Sternberg (1985), Gourlay (2004) suggest that these authors did not base their studies on M. Polanyi, and Collins even attested Wittgenstein greater significance. The table below provides an overview of current perception of tacit knowledge:

Example	Source
legal expertise - determining critical case factors; identifying precedents; developing analogies; building an argument	Marchant & Robinson 1999
knowing how to handle face to face selling; how to maximise high probability sales situations; salesman's rules of thumb	Wagner *et al.* 1999
setting up a scientific experiment - e.g. the care taken in clamping the apparatus; in preparing experimental materials (polishing a metal suspension thread; greasing a silk suspension thread)	Collins 2001a
riding a bicycle; dancing	Collins 2001b; Cook & Brown 1999
applying social rules; following conventions	Collins 2001b; Janik 1988
speaking acceptable phrases	Collins 2001a
"knowledge … manifested in traditions"	Collins 2001b; 1974
nurses intuitions about patients' conditions	Herbig *et al.* 2001; Josefson 1988; Leonard & Sensiper 1998
managing oneself (knowledge about the importance of tasks), and managing others (how to assign tasks)	Wagner & Sternberg 1986
deciding which journal to submit an article to	Wagner & Sternberg 1986
drawing inferences from various news stories	Baumard 1999
doctors' rules of thumb for psychosocial problems	André *et al.* 2002
making, and playing, musical instruments	Cook & Brown 1999
baker's ability to make tasty bread	Nonaka & Takeuchi 1995

Table 2: Knowledge that is tacit to knowers (Gourlay, 2004, p. 5)

When comparing the various uses of tacit knowledge, as summarised in the table above, it becomes clear that Gourlay's statement that the "*current tacit knowledge theory is weak or ambiguous*" (Gourlay, 2004, p. 4) is neither too bold nor farfetched. Gourlay identifies four main categories:

- knowledge where knowers are unaware;
- knowledge that was previously explicitly known;
- innate knowledge;
- knowledge that some actors can tell, but others cannot because they are unaware of it (Gourlay, 2004, p. 4).

Two of these categories require further explanation: innate knowledge and knowledge that was previously explicitly known. Innate knowledge is 'knowledge' that everyone is born with, such as motor skills (M. Polanyi attributed the ability to ride a bike to tacit knowledge). Previously explicit knowledge (documented knowledge) refers to knowledge that, according to Nonaka & Takeuchi, can be internalised or absorbed by experiencing the experience of others if, and only if, this experience has been specially ‘prepared’ for easy ‘absorption’. With regard to tacit knowledge as a phenomenon that solely can be attributed to individuals[19], Gourlay has identified six distinguishing categories:

a) someone can do something, but apparently cannot give an account
b) someone claims they feel something of which they cannot give an account, but it is not clear if subsequent events validate the claim
c) someone can do something, but not give an account at that moment, but can, if pressed, recall the explicit knowledge that was used tacitly when acting
d) knowledge existing prior to the situation in which it is effective, and due to innate (biological) characteristics
e) knowledge existing prior to the situation in which it is effective, and due to cultural factors
f) situations where A knows something that B does not, but where it could be argued A and B share the same practice (Gourlay 2004, p. 9).

Gourlay suggests that “*not to use the phrase [tacit knowledge, sic!] where there is no question of the knower not being able to say, either because they are explicitly aware of something (it’s just that someone else is not), or where they can readily bring the explicit knowledge that underpins their behaviour to mind (experts).*” (Gourlay, 2004, p. 11). Although Gourlay refers in this example to experts, his notion of experts should not be confused with expert knowledge and the underlying tacit component as described throughout this thesis. In other words, Gourlay suggests that the notion of tacit knowledge should not be used where experts can recall the explicit knowledge that is required to carry out a task. This is different to expert knowledge that is based on the synthesis of explicit (theoretical) knowledge and tacit practical (expert) knowledge acquired over a lengthy period of time. See also Chapter 3.4 on expert knowledge.

[19] This excludes forms or categories of collective or organisational tacit knowledge.

After having discussed tacit knowledge in its various forms and interpretations, it should also be mentioned what tacit knowledge is not. The often quoted examples of tacit knowledge that M. Polanyi provided, knowing how to ride a bicycle or knowing how to swim, are by definition not forms of tacit knowledge. Here, M. Polanyi has simply been wrong, as these are motor skills and fall into the area of innate knowledge; the knowledge people are born with. The other rather obvious example that cannot be attributed to tacit knowledge is the ability to master language. Language is a cognitive capacity and as such also inherent to us since birth.

3.3.2 Explicit knowledge

Explicit knowledge is *de facto* the opposite of tacit knowledge. For M. Polanyi, explicit knowledge is defined as knowledge that can be 'clearly stated' (Polanyi M. , 2000). In an organisational context, explicit knowledge is basically all documented, archived and codified knowledge that can be held in databases, technical specifications, patents, policies and procedures, etc. In other words, and, as Bock put it, explicit knowledge is "*the knowledge that is out there for all to find, see and use*" (Bock 2000). In terms of knowledge generation, it is the knowledge that can be easily documented, be it by adding meaning to data and then value to information or by simply writing down some meeting minutes and placing it on a black board, an Intranet or the Internet. However, explicit knowledge must not be confused with either free information or commercial information, as defined by Keohane and Nye (1998) for instance. Just because something is 'out there and for everyone to find', does not mean that it is explicit knowledge.

3.3.3 Transforming tacit to explicit knowledge

As discussed previously, tacit knowledge is the knowledge that someone has in his/her head. This tacit knowledge has not yet been documented and is linked to knowledge by acquaintance and expertise. This limits the transferability and thus hinders public access to that type of knowledge. Most importantly, tacit knowledge is always controlled by the person or the organisation that has it. A few researchers also argue that tacit knowledge is simply impossible to convert into explicit, and therefore, documented knowledge (Tiessen, Andriessen, & Deprez, 2000). Cowan *et al.* (1998) are more specific in this regard and make the distinction between tacit knowledge that is:

- tacit for lack of incentives
- tacit by nature.

According to this, tacit knowledge that has not been documented due to a lack of incentives can actually be transferred into explicit knowledge. An example is work-routine or process mapping, no matter the complexity. Until a certain work routine (especially when it is a new, or a very old, but undocumented one) has been documented, the knowledge of how to perform this particular task might reside only in few people's minds. With sufficient expertise on how to properly transfer this particular knowledge, this existing tacit knowledge can be made explicit. The outcome, however, and especially the quality and usefulness always depends on the expertise of the person that was tasked to perform this transfer. But there are also examples for 'undocumentable' knowledge, which is tacit by nature. For instance, one cannot convert one's tacit knowledge and understanding (and certainty) of colours into explicit knowledge. For instance, when one sees a green object, it is 'known' that this object is green. One cannot, however, document into the finest details as to why one knows that this particular object is green. All that is known is that one has 'come to known this colour as being called green' and ever since this colour was associated the adjective green.

In the academic discussion concerning as to whether tacit knowledge can be transferred into explicit knowledge, the opinions vary starkly. Nonaka and Takeuchi (1995) advocate that, by absorbing the experience of others, tacit knowledge can be converted into explicit knowledge, although this process has its difficulties. Von Krogh (1996) doubts that this is possible, as tacit knowledge is knowledge that cannot be communicated. Tiessen, Andiessen and Deprez (2000) seem to agree. Baumard (1999) on the other hand, provides a rather mixed account. Although Baumard agrees that tacit knowledge is not communicable, by using patents as examples, he ultimately also implies that there must be a conversion process from tacit knowledge (say the 'invention') to the patented description. Gourlay (2002), albeit not convinced of

Nonaka and Takeuchi's approach, refers to Collins (2001) who has researched the role of tacit knowledge amongst scientists and other skilled professionals. Collins argues that tacit knowledge can be passed on between scientists (or other professionals for that matter) by means of direct contact, but not in any documented (written instructions, diagrams, etc.) form. The below lists types of such knowledge as identified by Collins (2001 in Gourlay, 2002):

- concealed knowledge: tricks of the trade; concealment may be intentional or unintentional (the concealer is unaware)
- mismatched salience: different parties focus on different variables or aspects of a complex piece of research, resulting in mismatched perspectives
- ostensive knowledge: words may not be available to convey knowledge that pointing can
- unrecognized knowledge: the successful experimenter may be unaware of critical actions that an observer successfully but unconsciously imitates
- uncognized/uncognizable knowledge: our ability to utter meaningful sentences without being able to say how; learning requires apprenticeship (Gourlay, 2002, p. 6).

As Gourlay (2002) concludes, all but the last example, which also resembles the aforementioned inability to describe exactly why one calls colours by their designated names, can be converted into explicit knowledge. Nevertheless, by going back to Cowan's reasons for tacitness, that are tacit for lack of incentives and tacit by nature, further reasons as to why tacit knowledge may be difficult or even impossible to transfer shall be explored. Three additional motives are:

- concern with secrecy and power,
- because no one has bothered to recognize the knowledge or tried to explicate it, and,
- because it concerns presuppositions we all generally hold (Gourlay, 2002, p. 5).

The latter two can be compared to the group of tacit knowledge that remains tacit for the lack of the proper incentives. To a certain extent, however, the same could also be said about tacit knowledge that is not shared for reasons of power and secrecy. Here, a lack of incentives could be explained by the fact that holders of this particular knowledge might either not have a reason to give this knowledge away (i.e. for reason of his/her own personal status) or that he/she may not be allowed to do so, for instance by having to sign non-disclosure agreements (NDAs).

3.4 Expert knowledge and knowledge gaps

3.4.1 Expert knowledge

Expert knowledge has received much attention in recent years. Apart from the fact that experts are often recognised for their reliability to interpret special issues, experts are also regarded as authorities (also see the aforementioned authoritative mode of knowledge). Barely a single day goes by without an 'expert' being questioned on TV, on radio shows or in the print/online media on a broad variety of issues, most of them highly topical. Nowadays, there are 'immigration experts', 'climate change experts' and even 'fashion experts' who are often presented to the public in order to explain to the layperson - which by definition is the opposite of an expert – complex issues or that simply debate with other authorities in their respective fields. One underlying assumption, that the public accepts experts for their knowledge, is often understood to be a given. Popular TV news coverage in the majority of industrialised countries has grown accustomed to having a pool of experts on stand-by, should the need arise.[20] Whether the content of what is presented by the popular media can be regarded as expertise is questionable. It is more likely that, although a number of experts are indeed representing an expert opinion, the majority of issues debated scratch mostly only the surface of an underlying expertise. Nonetheless, the target audience of these media events is the layperson, who is often challenged enough by what is presented or who simply does not have the time and interest to care.

> What transforms a scientific statement into an expert opinion is its use in the decision-making process. From then on the scientist cannot avoid bringing something of himself or herself into the process: his or her personal and

[20] Although no current data could be found, it is probably not too bold to assume that are not many UK universities that do not have one of those 'stand-by' experts.

professional background, his or her sympathies, and so on. The objectivity expected of him or her has to be maintained not only despite pressures from the public or from government, but also, no matter how honest he or she is, despite his or her prejudices and commitment. In short, a clear distinction must be made between three separate functions: producing knowledge, offering an expert opinion and making decisions (Salomon, 2001, pp. 220-221).

In addition to the use of expert knowledge in the decision-making process, expert knowledge is also used as proof, or as it is called, expert testimony, in courts. The idea behind this is to make knowledge usable and accessible to a jury, for instance, that normally would be outside their ability to comprehend. As a result, expert testimony "*must be stated in the language of general coherence, …, but that language must rely on formalized models, in addition to common sense and other intuitive preconceptions*" (Page & Lopatka, 2004, p. 12). However, there are some fears that expert testimony may be too complex for juries to either fully understand, or when case-specific, to put it correctly in context. Thus, and without debating any legal framework (i.e. what expert testimony must adhere to, or whether and under which circumstances expert testimony is admissible or should be rejected), one fact needs to be acknowledged: expert testimony follows the authoritative mode of knowledge, based on experts' qualifications, reliability, fit and/or reputation (Page & Lopatka, 2004). As a result, relying on expert testimony always assumes that the expert in question acts in court and exercises the same intellectual capacities that they would employ in their respective field of expertise (Page & Lopatka, 2004). A US court case shall be used as an example to illustrate the discussion above: Kumo Tire Co. Ltd. vs. Carmichael. Following an accident, where a car tyre failed with the result of overturning the van, the Carmichael family sued the manufacturer Kumo Tire Co. Ltd.

> The Carmichaels hired George Edwards, an expert on tire failure, to examine the tire. Edwards concluded that a defect in the tire's design or manufacture caused the blowout. Before he could testify for the Carmichaels, Edwards became ill. He passed the case on to his employee, Dennis Carlson, who was also a credentialed expert on tire failure. Carlson reviewed Edwards file on the

tire and discussed the case with Edwards. He then confirmed Edwards' conclusion that the tire was defective. Carlson did not examine the tire until after he had rendered his opinion on the cause of the blowout, but he claimed that the examination confirmed his earlier conclusion (Bernstein, 1998, pp. 7-8).

As a result of this, Kumo Tire Co. Ltd. asked the court not to allow Carlson to testify at the trial. Although neither Carlson's qualifications nor his fit was questioned, but the fact that he came to a conclusion before examining the evidence and thus, the expert testimony failed the acceptable standards[21] (Bernstein, 1998). In other words, although the expert exercised an authoritative mode of knowledge, he did not apply the same intellectual capacities that he normally would employ in his respective field of expertise on a day-to-day basis. The result was that the 'authoritative stance', which is normally purposefully employed in order to exercise the expert testimony, was rejected. In other words, the expert – as an authority – lost exactly that: authority.

This example could easily be translated into the area of politics, for instance instead of expertise on car tyres, this could be expertise on nanoscale silver particles, and instead of a court it could be a hearing during a policy formation process. Both scenarios rely on sufficiency and reliability of the expert and therefore on its authority (Page & Lopatka, 2004).

To clarify what can and cannot be expected of experts, Boynton (2007) delivers a very practical (and in this instance, perhaps coincidentally, non-academic) hands-on 'can' and 'can't' do list with regards to when to use expert advice. According to Boynton, experts:

Can…

- Provide information about their research, area of teaching, or clinical practice.
- Discuss issues within their area of expertise (for example their branch of science, …).

[21] In the US, these standards were established following three main court cases: Daubert v. Merrell Dow Pharmaceuticals, Inc., General Electric Co. v. Joiner, and Kumo Tire Co. v. Carmichael (Gross & Mnookin, 2003).

- Reflect on other research projects or ideas expressed by others in their field.
- Provide journalists and the public with information (e.g. results of their research, …).
- Use evidence or experience to suggest areas where academia, science, … can be improved.

Can't…

- Talk about the results or outcomes of any research they have conducted until it has been published, or is presented at a conference.
- Discuss the results of other people's work before they have presented or published it.
- Make claims that go beyond their data.
- Talk outside their area of research, practice, and expertise (Boynton, 2007).

The above list of items experts can do seems obvious and self-explanatory. The same, however, cannot be said about the list of things experts cannot do. The first point, not to talk about unpublished and peer-reviewed finding may be well understood in academia, yet as to whether every expert takes this seriously is questionable. A good example is the use of experts by the media on newsworthy day-to-day events, for instance the latest military coup or the failures of a company that has just published its annual fiscal report. In these instances, when an expert comments on these events, the experts have not actually carried out research on either of these subject, but instead, drew conclusions and gave advice based on previous experience in similar circumstances. Although, this is not to say that an expert cannot be correct by inferring from his/her previous experience, the problem here is that, in fact, it is mere assumptions that are presented by following an authoritarian mode of knowledge dissemination. A layperson, in these instances, may not be able to distinguish between what is scientific evidence and what is conjecture, yet is presented an 'expert opinion'. When summarising her list, Boynton argues that experts are "*bound by particular ethical and professional guidelines, so the 'can't do' section of this list isn't something that should be seen as optional*" (Boynton, 2007).

A different take on the subject is presented by Geißel and Penrose (2003). Since the mid-1990s, according to Geißel and Penrose, there has been increasing criticism over the lack of participation possibilities of the general public in political decision-making processes as well as in the processes of knowledge production. This could be observed as follows: society modernised itself by also increasing its general levels of education, yet at the same time, society has less and less accepted statements of political and scientific experts. This is mostly expressed by a general doubt and distrust towards the neutrality and objectivity of political and scientific expertise. One the one hand, Geißel and Penrose point out, there is the general fear that results of scientific expertise has been influenced by economic or political factors. On the other hand, there is the insecurity of the public about their own ability to understand and correctly interpret scientific results. Both of these arguments cumulate in a general assumption prevalent in the public mind that scientific expertise can always be countered by means of employing counter-expertise. Geißel and Penrose conclude that this results in science looking incomplete, contradictory and elitist.

3.4.2 Knowledge gaps

At the moment, there are no definitions available that describe what knowledge gaps are or that somehow define the parameters that constitute knowledge gaps. Does the lack of the public's understanding of nanotechnology, for instance, constitute a knowledge gap? Similarly, is the lacking knowledge by a politician with regards to the genotoxicity of nanosilver particles to be understood as a knowledge gap? In general, one can argue that knowledge gaps occur when parts of a process or sequence are unknown to the performer. These knowledge gaps can refer to both, theoretical knowledge and practical knowledge. Also, the term 'knowledge gap' makes most sense when used to describe 'lacking knowledge' by acquaintance, as there is potentially no limit to the lacking knowledge of description. At the same time, lacking knowledge of description is not really an issue, as it has been established; knowledge by acquaintance is epistemically prior[22]. Thus, the questions posed above have to be

[22] That is, in the context the research topic. However, a pupil in school who lacks knowledge by description during a multiple choice test, can, for obvious reasons, be perceived as an issue.

answered with a no, as it cannot be expected that either the public or politicians possess such knowledge.

However, the issue of knowledge gaps is not limited to cases where sufficient knowledge and expertise cannot be used or is available. It also encompasses the areas where the required expertise cannot simply be transferred to the public so that they can form an informed opinion. Examples of the limits to transferring tacit to explicit knowledge have been shown above (see Chapter 3.3.). The latter case bears a larger weight when taking current issues of the 'politics-tiredness' of the general public into account, as well as current doubts on the general ability of democracy to tackle contemporary issues.

3.5 Information, knowledge and policy making

3.5.1 Policy making

Due to the vast changes that have occurred in the last century (see also Chapter 2) Mehan (1993) suggests that *"[a]radical change in both the kind of knowledge sought by policy-analysts and the way in which such knowledge is used in policy-making is essential"* (Meehan, 1993, p. 54). By this, Mehan refers to both a better conception of the kind or type knowledge relevant for policy-making and criteria that can be used to validate knowledge claims. Policy-making itself has received much attention in the last two to three decades. What initially began with Lerner and Lasswell (1951) soon begun to split into several subfields within the political sciences. According to Sabatier (2001), policy research by political scientists mainly followed four routes:

- Substantive area research
- Evaluation and impact studies
- The study of the policy process
- The study of policy design

Substantive area research focuses on policy of specific areas, such as social policy, education or environmental policy. As such, case studies often aim to help both practitioners and policy activists (Sabatier, 1991b). Evaluation and impact studies, on the other hand, not only rely on contributions from other disciplines (often economics) but also go beyond standard cost-benefit analyses. Sabatier (1991) points out that evaluation and impact studies have become integrated into research on the policy process by examining the advantages and disadvantages of the use of policy analysis in the real world. Somewhat differently, the study of the policy process emphasises "*factors affecting policy formulation and implementation, as well as the subsequent effects of policy*" (Sabatier, 1991b, p. 144). Sabatier refers to Ranney (1968) and Sharkansky (1970), who argue that "*substantive policy areas risked falling into the relatively fruitless realm of atheoretical case studies, while evaluation research offered little promise for a discipline without clear normative standards of good policy. A focus on the policy process would provide opportunities for applying and integrating the discipline's accumulated knowledge concerning political behavior in various institutional settings*" (Sabatier, 1991b, p. 144). Finally, policy design focuses on different types of policy instruments, such as regulations, standards, incentives and others.

Each of the above-mentioned areas of inquiry can be broken down further into a number of sub-fields and specialisms. For instance, the study of the policy-process, which - in Sabatier's opinion - has been the "*most fruitful*" (Sabatier, 1991b, p. 144), could be broken down into:

- agenda setting
- formulation and adoption
- implementation and
- evaluation.

The same could be done by looking at different types of substantive area research, evaluation and impact studies or the study of policy design. What is more, further distinctions could be made by looking at different approaches to the policy process, be they of heuristic or of normative nature, activist based or purely theoretical. All in all, this also has led to some criticism on policy research. The most serious one is that "*policy scholars have made only modest contributions to developing reasonably clear, generalizable and empirically verified theories of the policy process*" (Sabatier, 1991b, p. 145):

> Much of what passes as policy research-particularly by substantive area specialists-shares all the defects of traditional case studies in public administration: descriptive analyses of specific institutions or decisions relying upon very subjective methods of data acquisition and analysis, virtually no attention to the theoretical assumptions underlying the research or the theoretical implications of the findings, and very little concern with the potential generalizability of those findings (Sabatier, 1991b, p. 145).

This criticism requires a deeper look into theories of the policy process. In particular, three different approaches shall be examined here. However, there are also other approaches to and theories of the policy process. Sabatier (1991) provides an overview and refers to Hofferbert's 'open-systems framework', Kingdon's 'policy stream framework' and Wildavsky's 'cultural explanations of policy change' (Sabatier, 1991b). Although the three theories that have been selected are all rationalist approaches, they have been chose over others (for instance, Lassall's (1956) heuristic stages model) because they account for criteria that are important to this thesis. Overman states that "*[t]he role of theory in the policy sciences oscillates between useless and useful, futile and fruitful depending on our perspective,…*" (Overman, 1988, p. 109), the three chosen approaches are not only useful, but will also shed some light on the role information and knowledge play when actors are faces with uncertainty. The first of the chosen approaches focuses on the role of institutions in shaping information processes, the second looks at how actor interests drive their behaviour towards such processes and the third emphasises the role of beliefs and secondary knowledge/information.

3.5.2 Theories of the policy process

The first of the three approaches discussed here is that of Ostrom (1991), who advocates an Institutional Rational Choice (IRC) approach. For IRC theorists, such as Ostrom, public policies are institutional arrangements and policy changes are the result of individuals trying to improve/alter a given situation by changing institutional arrangements. These arrangements include presumptions about how actors behave and a number of key characteristics of decision situations. Therefore, according to Ostrom, actors need to specify their:

- resources
- ability to process information
- valuation of outcomes and actions
- criteria for selecting actions (Ostrom, 1990, 1991)

In addition, Ostrom defines decision situations that include institutional arrangements, for instance, the rules that define what actions are allowed, required and/or forbidden. Furthermore, since policy making always happens in the physical, real world, these attributes are important, as well as characteristics of the locale within which desired action is taking place. "*Since in most cases, actors cannot readily change the characteristic of the community or the relevant attributes of the world, they direct their efforts to realize their preferences and improve their situations at changing institutional arrangements*" (Schlager & Blomquist, 1996, p. 653). Therefore, ICR define policy changes as actions taken at institutional level, whereby the actions themselves are grouped into different levels. For instance, actions to change existing institutional arrangements are one level of actions; the introduction of new, previously not existing rules is another level of actions. All in all, there are three levels of actions:

- operational, having to do with the direct actions of individuals in relating to each other and the physical world;
- collective-choice, the level at which individuals establish the rules that govern their operational-level actions; and
- constitutional, the level at which individuals establish the rules and procedures for taking authoritative collective decisions (Schlager & Blomquist, 1996, p. 654).

Within that model, actors can either move between these different levels, or decide to influence only one level of actions. From an IRC perspective, policy changes happen at the collective choice or the constitutional level in order to change institutional arrangements. In the context of this thesis, one could interpret Ostrom's approach as follows: actors working on nanotechnology could be working on any of the three levels, always knowing that the choice outcome of one level affects the next (constitutional - collective - operational level). In other words, actions taken at the constitutional level, the level where the rules and procedures are set, impact actions that follow at the collective choice level, the level where policy change is made.

The second approach to a theory of the policy process is that of Moe's Politics of Structural Choice. Moe (1995) also perceives policy changes as changes to institutional arrangements. However, these changes aim to overcome collective action problems and require cooperation for mutual gains. One of the main premises of Moe's argument is that the lack of information/expertise leads to use of interest groups, with the result that different political actors have different motivations. On the other hand, it is only because of the interaction of interest groups, politicians and bureaucrats that leads to the formation of public policy (Schlager & Blomquist, 1996).

> The result is a two-tiered hierarchy: one tier is the internal hierarchy of the agency, the other is the political control structure linking it to politicians and groups. If we think of business firms as governance structures that include their creators, then, the closest analogy in the public sector is not the public agency itself, but rather this extended hierarchy of public authority that begins at the top with politicians and interest groups and moves down to bureaucratic leaders to the lowest reaches of the organisation (Moe, 1995, p. 122).

Within this model, Moe explores how political actors achieve their goals and how they maintain their power and influence. For instance, interest groups may be politically successful today, but this may not last. Thus, even though an interest group may be powerful enough to establish a new agency, the same interest group may not be in existence when it finally comes to the implementation of policy, and new actors may arise and change the direction (Moe, 1995). As a result, political change affects institutional design. Thus, in order to "*to gain even a portion of what it wants, those seeking political control must engage in compromise even with adversaries*" (Schlager & Blomquist, 1996, p. 655). This 'twin pressure' of political compromise and uncertainty is a key characteristic of Moe approach. In the context of this thesis, one could interpret Moe's approach as follows: the various actors working on nanotechnology have an expectation that other groups and actors will bring in counter-arguments and points, thus destroying or compromising technical expertise in favour of political compromise.

The third approach is that of Sabatier's Advocacy Coalitions. Sabatier views policy change as a function of:

- the interaction of competing advocacy coalitions within a policy subsystem
- changes external to the subsystem
- the effects of relatively stable system parameters (Sabatier, 1991b).

An advocacy coalition consists of actors from both public and private organisation that share a common set of basic beliefs (policy goals) who "*seek to manipulate the rules of various governmental institutions to achieve those goals over time*" (Sabatier, 1991b, pp. 152-3).

> Coalitions are assumed to organize around common core beliefs, such as the proper scope of governmental vs. market activity and the proper distribution of authority among levels of government. Since these core beliefs are hypothesized to be relatively stable over periods of a decade or more, so too is coalition composition. Coalitions seek to learn about how the world operates and the effects of various governmental interventions in order to realize their goals over time. Because of resistance to changing core beliefs, such policy-oriented learning is usually confined to the secondary aspects of belief systems (Sabatier, 1991b, p. 153).

Socio-economic conditions, for example, are what Sabatier means by 'subsystems' and his 'system parameters' refer to basic social structures and constitutional rules. Because advocacy coalitions are based on a shared belief system, they operate by:

- developing and using information in an advocacy mode to persuade decision-makers to adopt policy alternatives supported by the coalition
- manipulating the choice of decision-making forum

- supporting public officials in positions of public authority who share their views or may even be members of the coalition (Schlager & Blomquist, 1996).

For the advocacy coalition framework, information and learning are important motivating factors. As a result, the process of policy change is a constant "*iterative process of policy formulation, problematic implementation and struggles over reformulation*" (Sabatier, 1988, p.130 quoted in Schlager & Blomquist, 1996, p. 657). Schlager and Blomquist argue that the advocacy coalition framework is best suited to explain policy changes that appear over decades, as it focuses on policy changes resulting from changing preference or beliefs participating actors, instead of explaining change as a result or consequence of emerging new actors that have different sets of preferences (Schlager & Blomquist, 1996). In the context of this thesis, Sabatier's approach could be interpreted as follows: a range of actors working on nanotechnology have not only the same core policy beliefs, but will attempt to make policy change happened through coordinated activity, consisting of, amongst many other strategies, influencing like-minded decision-makers, the use of mass media to change public opinions, and the use of information to change perceptions of polices.

Following Schlager and Blomquists' (1996) research, the differences of the three approaches can be compared by looking at six criteria:

- the boundaries of inquiry
- the model of the individual
- the roles of information and beliefs in decision making and strategy
- the nature and role of groups
- the concept of levels of action
- the ability to explain action at various stages of the policy process.

Table 3, below, provides an overview of the differences in the three approaches. Two of the above six areas are of particular interest of this thesis and will therefore be examined in more detail (see also Chapters 3.6 and 6).

Criteria	Institutional Rational Choice	Structural Choice	Advocacy Coalitions
Boundaries of Inquiry	The decision situation and individuals	Typically, a public organization plus its creators, benefactors and administrators	Policy subsystem organized around policy problems
Model of the Individual	Intendedly but boundedly rational problem-solver	Substantively rational maximizer seeking power	Procedurally rational acting on information and beliefs
Uncertainty, Information and Belief	Actors use search and trial-and-error learning to reduce uncertainty. beliefs enter in as attributes of the community, affecting the costs & benefits of options	Actors' behavior driven largely by political uncertainty. Interests emphasized over beliefs as motivations for actors' behavior	Accumulation and use of information a key element of policy change. Actors' beliefs serve as perceptual filters in their receipt of information, but information can also change beliefs
Nature and Role of Groups	Groups are not central to IRC explanations and collective action barriers to group formation emphasized	Groups are central to political action, but their formation is assumed rather than explained. Groups and politicians exchange political support for favorable policies	Coalitions, which include interest groups, are central actors and cohere around beliefs. Process of coalition formation is assumed rather than explained
Levels of Action	Explicitly made part of actors' coalitions' strategic behavior; policy change conceived as rule change	Implicitly included in explanation; however, most of the time, rules of the political game assumed fixed	Implicitly part of the strategic behavior in attempt to influence choice of decision making forum
Stages of the Policy Process	Emphasis on problem definition, policy formulation, evaluation	Emphasis on adoption stage	Emphasis on problem definition, policy formulation, adoption, evaluation

Table 3: Comparing approaches to three emerging theories of the policy process (Schlager & Blomquist, 1996, p. 659)

Ultimately, "[t]*he goal of a political theory of the policy process is to explain how interested political actors interact within political institutions to produce, implement, evaluate, and revise public policies*" (Schlager & Blomquist, 1996, p. 653). Therefore, one area of the three previously introduced approaches to policy theory shall be used and applied against the findings of this chapter. In particular, Ostrom's Institutional

Rational Choice (1991), Moe's (1995) and Sabatier's Advocacy Coalitions Framework (1991) will be analysed with respect towards:

- the roles of uncertainty, information and beliefs in decision making and strategy

The table below summarises the assumptions these three theories make with regards to uncertainty, information and beliefs:

Criteria	Institutional Rational Choice	Structural Choice	Advocacy Coalitions Framework
Uncertainty, information and beliefs	Actors use search and trial-and error learning to reduce uncertainty. Beliefs enter in a s attributes of the community, affecting the cost and benefits of options	Actors' behaviour largely driven by political uncertainty. Interests emphasised over beliefs as motivations for actors' behaviour.	Accumulation and use of information is a key element of policy change. Actors' beliefs serve as perceptual filters in their receipt of information, but information can also change beliefs.

Table 4: Summary of the information aspect of theories of the policy process according to Schlager & Blomquist (1996).

Although beliefs and belief systems are not the central focus of this thesis, beliefs can be influenced by both information and knowledge. For instance, although particular beliefs can have an impact on policy preferences, an additional supply of information either does not change a person's belief or it only reinforces this belief. In the example provided by Kahan *et al.*, a person that was particularly Green/eco-friendly or conservative did not change their opinion about nanotechnology when supplied with more information (Kahan, Slovic, Braman, Gastil, & Cohen, 2007). Keohane supports this view:

> Facts don't necessarily have the power to change our minds. In fact, quite the opposite. In a series of studies in 2005 and 2006, researchers at the University of Michigan found that when misinformed people, particularly political

> partisans, were exposed to corrected facts in news stories, they rarely changed their minds. In fact, they often became even more strongly set in their beliefs (Keohane J. , 2010).

In both Ostrom's IRC and Moe's Structural Choice framework, information has a relatively narrow role; the use of information in decision-making processes is selective due to the limited information processing capabilities of individuals. Although Ostrom stresses the role of information, it is mainly used in the context of individual information-processing capacities (Ostrom, Gardner, & Walker, 1994). In order to identify how actors make decisions, the term information is used as measure to determine the level of information actors can possess and process. For instance, by making the assumption that actors have complete and all-encompassing information, an ideal scenario outcome would be that actors "*know the full decision or game tree in extensive form. Perfect information requires all aspects of complete information, and in addition, that all actions taken by participants are known to all others*" (Ostrom, Gardner, & Walker, 1994, p. 34). By making the assumption that actors have complete information and infallible information processing capabilities, various models can then be assessed. By doing this, and by applying 'bounded rationality', that is to say, a much weaker assumption about actors' information processing capabilities, the result is that actors make mistakes, for instance, by processing only some, or even none of the information that is available. A similar effect can be achieved by manipulating the number of actors involved is such a scenario. Ultimately, what is important in the context of this thesis is the use of the term information. Making any of the above assumptions is perfectly fine – within the context of Ostrom's model. What is open to debate is the lacking specificity of the term information. How this can be interpreted with regards to nanotechnology will be discussed in detail in Chapter 6.4 of the analysis section of this thesis.

Moe stresses that in situations of uncertainty there is an expertise problem since science and social science still doesn't know enough: "*These knowledge problems are compounded by uncertainty about the future*" (Moe, 1995, p. 132). Moe argues that political uncertainty differs from economic uncertainty due to the fact that political property rights – for instance the right to exercise public authority – cannot be claimed by individual actors or groups of actors in perpetuity: "*whatever policies and structures ... put in place today may be subject to authoritative direction of other actors tomorrow, actors with very different interests who could undermine or destroy their hard-won achievements*" (Moe, 1995, p. 124). The result of this is political compromise, as most of the struggle will be about who has the rights "*to make authoritative decisions for society*" (Moe, 1995, p. 125). Thus, political uncertainty leads to questions about how to protect political governance structures from opponents, and not how to design the most efficient way of governance.

The information and knowledge problem becomes apparent by what Moe calls the 'technical problem of structural choice' (Moe, 1995). That is, for instance, if a dominant political group wants to exercise its power, it is usually quite successful in simple decision-making circumstances. In complex ones, however, it lacks the knowledge to do so. As Moe put it, the dominant group "*typically knows much less than society does, even when it hires its own experts*" (Moe, 1995, p. 132). Here, a solution could be for the dominant group to work on legalisation, for instance, in very general terms and leave to specifics to experts. This would allow for the group to focus on its core skills and would compensate "*nicely for the group's formidable knowledge problems*" (Moe, 1995, p. 133). This, however, has major issues for the dominant group. On the one hand, it would create an expertise dependency that might even challenge the dominance of the dominant group. On the other hand, it creates a legitimacy problem, as the dominant group could not explain to the public, for instance, why exactly they made the decisions the way they did. What this means to the specific nanotechnology case of this thesis will be discussed in Chapter 6.4.

In Sabatier's AC framework, the role information plays is much more sophisticated. Sabatier stresses "*the crucial role of information and (policy) analysis … [that aims] to alert people to the extent to which a given situation affects their interests/values*" (Sabatier, 1988, p. 152). In their analysis of various theories of the policy process, Schlager and Blomquist attest that information can be used as part of the socialisation process by advocacy coalitions "*for recruiting and adding members, for reinforcing the* *views of existing members, and for increasing the congruence of members' perceptions of their goals and policy preferences*" (Schlager & Blomquist, 1996, p. 662). Therefore, information is not only being used as a means to overcome uncertainty when faced with policy-choices, but instead, it is used much earlier in the process. When looking at the findings of Oh and Rich (1996), who argue that familiarity with a policy problem often reinforces a policy-makers' stance on a problem while unfamiliarity does not, the use of information in the instance of an advocacy coalitions seems to somewhat suggest that, at least, part of this unfamiliarity can or should be overcome by reinforcing existing group views. In other words, people with common understandings or beliefs are more likely to agree on collective action than those with opposing or differing opinions. This may also explain why in advocacy coalitions, the interaction of information and beliefs is central. Depending on the viewpoint of an advocacy coalition, information can either be integrated or rejected, thus the term 'perceptual filter'.

> The AC framework incorporates the deliberate cultivation and accumulation of information within the array of coalition actions. Indeed, the "advocacy" part of the AC explanation for policy change represents the conviction that coalitions in the policy process devote considerable resources to the development and deployment of policy information that supports their views, and that such activities matter (Schlager & Blomquist, 1996, p. 663).

The perhaps most important point of the AC framework is that of policy-oriented learning. As Sabatier puts it "*'knowledge does not suddenly appear, become universally accepted, and suggest unequivocal changes in governmental action programs. Instead, findings challenging the accepted wisdom concerning the seriousness of a given problem and its principal causes tend to emerge gradually over time, be challenged by those who perceive their interests to be adversely affected, and thus give rise to the sort of analytical debate…"* (Sabatier, 1988, p. 154). This policy-oriented learning appears mostly when there is an intermediate-level conflict across varying actors, that is, a conflict that is not about core values, but more likely about technical aspects, data interpretations and information usage. Finally, as part of developing the AC framework, Sabatier proposes a number of hypotheses. One is of particular interest here: "*Problems for which accepted quantitative performance indicators exist are more conducive to policy-oriented learning than those in which performance indicators are generally qualitative and quite subjective*" (Sabatier, 1988, p. 156). The term qualitative performance indication can be translated as qualitative data and information. How Sabatier's use of the term information and data can be interpreted with regards to nanotechnology will be discussed in Chapter 6.4.

In general, the role of policy information, or to be more precise, policy information and policy knowledge requires further examination. Similarly, the nature and the role of groups involved in policy making, that is, experts in the context of this thesis requires a further look.

> The inadequacy of the present knowledge supply tends to be masked by the common practice of confusing knowledge with information. … The present inability of academia to provide the knowledge that policy-making requires is too often ignored. … The implication is clear: the policy-maker should rely primarily on the resources available internally, using them to direct inquiries that will produce precisely what is needed (Meehan, 1993, p. 70).

What Meehan refers to is the laymen-like substitution of the term knowledge with information, and *vice versa*.

3.5.3 Policy information and policy knowledge

Both information and knowledge are used by governments and policy makers for a variety of reasons and purposes. Policy information "*can be used in the formulation of public policies, by helping to identify the need for a public policy, or to select one amongst alternatives*" (Straf, 2001, p. 11560). In addition, it can be used to evaluate and implement policies and to measure their impacts. Straf argues that "*[p]olicy information differs from political information, such as polls of public opinions, or support for a policy among legislators. Policy information is objective. It may be quantitative or qualitative, but it is based on evidence…*" (Straf, 2001, p. 11560). Straf's understanding is that policy information is both data and analysis, or better said, that policy information is often the result of policy analysis, which, in turn, can be understood as the evaluation of the social and economic implications of changes in public policy (Straf, 2001). P.M. Haas calls knowledge that can be used in policy-making usable knowledge: *"In short, usable knowledge encompasses a substantive core that makes it usable for policy-makers, and a procedural dimension that provides a mechanism for transmitting knowledge from the scientific community to the policy world and provides for agency when theorizing about broader patterns of social learning, policy-making, and international relations"* (Haas P. M., 2004, p. 573). P.M. Haas continues by arguing that "*usable knowledge is accurate information that is of use to politicians and policy-makers. It must be accurate and politically tractable for its users*" (Haas P. M., 2004, p. 574).

Sabatier also stresses the importance of policy information, as "[t]*he amount and quality of information used in choice situations has been a neglected topic - except in voting studies, …*" (Sabatier, 1991b, p. 148). The influence of information on policy decisions has been well documented. By referring to Patton (1978), Oh and Rich (1996) point out that decision makers use information to reduce uncertainty, especially when facing unfamiliar policy problems. The familiarity aspect, however, requires for distinctions to be made between where information comes from and what information is used when:

- a policy problem is old or familiar and
- a policy problem is an unknown.

According to Oh and Rich, if a policy problem is old or familiar, then it is very likely that information that is used comes from the decision makers own agency. This is because, when decision makers deal with problems with which they are familiar, they do not need to search for information, they know how to handle the problem and know where to find the information they require. In addition, "*since information from internal resources can be easily obtained and are believed to reinforce decision makers' positions on problems, it is more likely to be used*" (Oh & Rich, 1996, p. 12). This example is also called a closed cycle of information utilisation.

However, if decision makers face a policy problem with which they are unfamiliar with, their behaviour is quite different. When facing unfamiliar policy problems, decision makers tend to use more policy information in order to reduce uncertainty. What is more, the research by Oh and Rich points to a direct relation between the nature of the policy issue and the type of information used. "*This indicates that, when facing unfamiliar problems, decision makers tend to conduct a wide search of information beyond their own agencies*" (Oh & Rich, 1996, p. 12).

These observations, however, pose problems when looking at policy issues which are not only just emerging but are also of an incredibly complex nature. In the case of nanotechnology, for instance, a distinction needs to be made between available knowledge and usable knowledge, to use P.M. Haas' terminology.

> …the long time often necessary for developing credible knowledge may interfere with the short-term needs for applying the knowledge to making policy. In practice, then, existing knowledge is more likely to play a role in usable knowledge than is knowledge being developed concurrently with the policy process. (Haas P. M., 2004, p. 574).

This means that available knowledge, for instance research output or published material, is not ultimately useful for policy-making. Also, the distinction between information and knowledge needs to be kept in mind (see Chapters 3.1.2 and 3.1.3). Whereas information is a component of knowledge, knowledge – in order to be useful to the non-expert – needs to be translated back into useable information. P.M. Haas puts it as follows: "*This articulation of usable knowledge builds from prior efforts to formulate a sense of what kind of technical information is likely to be useful for policymaking relating to matters of complexity, which is also likely to be used by decision-makers*" (Haas P. M., 2004, p. 574).

3.6 Knowledge Framework

When it comes to making choices, and in particular, when it comes to policy choices, a framework for comparison is required. Meehan suggest that *"[s]ystematic comparison of the set of outcomes from which a choice is made, which lies at the heart of the* *justification process, requires a fairly sophisticated knowledge system. The available outcomes must be projected on the future…"* (Meehan, 1993, p. 56) . In the context of this thesis, this means the following. In order to assess the implications of the aforementioned knowledge types on nanotechnology, the chosen example of a knowledge-intensive and expertise dependent area of technology, a knowledge framework (see table below) has been devised. It is based on the findings highlighted in Chapter 3 (Knowledge, expertise and policy making) and is aimed to be applied against findings from Chapter 4 (Nanotechnology) and Chapter 5 (Nanologue), which provides relevant technical and empirical data. In particular, the knowledge framework enables the investigation of five different types of knowledge (knowledge by acquaintance, knowledge by description, tacit knowledge, explicit knowledge, and policy knowledge) that then will also be cross-referenced with qualitative and quantitative findings. In addition, the knowledge framework also supports further investigations of policy knowledge and policy information.

The empirical data provided by the Nanologue case (Chapter 5) will be applied against findings of the public's knowledge and involvement as well as against general recommendations, policy recommendations and recommended actions. Here, the aim is to identify 'knowable content' by groups of 'knowers' in order to derive at implications for both the public and the experts alike. Thus, the knowledge framework has been designed with the following proposition in mind:

> **If the involvement of the public in the discussion of future high technology areas is desired, then increasing knowledge-intensity and technological complexity and the resulting dependence on expert knowledge and advice will jeopardise this endeavour. The assumption is that the public has no first hand and thus direct knowledge, and even second-hand knowledge is only partially understood. The same also applies to policy making and the majority of policy-makers, who are not experts in the fields of nanotechnology.**

This proposition is used to investigate whether current recommendations made in the literature (Nanologue, 2006; Currall *et al.*,2006; RSA, 2004) are adequate in the light of the findings of this thesis.

	knowledge by acquaintance	tacit knowledge	knowledge by description	explicit knowledge	policy information and knowledge
Reitera-tion, what is what?	knowing things	knowing how (process of knowing)	knowing about things	easily accessible knowledge	usable knowledge/ information
Examples	Knowing how to perform a laboratory experiment.	Knowing how to perform a laboratory experiment.	Moscow is the capital of Russia.	handbooks, guidebooks, manuals	data + information required to make policy choices
Who?	skilled professional	skilled professional	skilled professional and layperson	skilled professional and layperson	decision-makers, agency staff
Nanotech case – what can be known?	detailed knowledge of properties of nanoscale silver particles, their behaviour and reactions to and with other elements	detailed knowledge of properties of nanoscale silver particles, their behaviour and reactions to and with other elements	existence of nanoscale silver particles and their alleged benefits as indicated by marketing material, press or other non-scientific releases	existence of nanoscale silver particles and their alleged benefits as indicated by marketing material, press or other non-scientific releases	existence of nanoscale silver particles and their alleged benefits as indicated by marketing material, press or other non-scientific releases
What cannot be known?	un-researched or undiscovered areas, behaviours and results, knowledge that is outside the domain of the knower	un-researched or undiscovered areas, behaviours and results, knowledge that is outside the domain of the knower	detailed knowledge of properties of nanoscale silver particles, their behaviour and reactions of other elements	detailed knowledge of properties of nanoscale silver particles, their behaviour and reactions of other elements	detailed knowledge of properties of nanoscale silver particles, their behaviour and reactions of other elements
Who?	chemists, physicists, material scientists with in-depths knowledge of nanotechnology	chemists, physicists, material scientists with in-depths knowledge of nanotechnology	laypersons and scientists alike	laypersons and scientists alike	laypersons, scientists, policy and decision-makers, lobby groups

Table 5: Knowledge framework

The above table starts off with a reiteration of what the different knowledge types are and gives an example according to their meaning and reach as well as showing to whom the respective types of knowledge apply. For instance, knowledge by description can be described as knowing about things, it applies to laypersons and professionals alike and an example is to ‘know’ that the capital of Russia is Moscow. It needs to be noted that the examples provided for what can be known and by whom are examples only and are by no means exhaustive.

With regards to the nanotechnology case, and in particular with regards to nanosilver, the knowledge framework can be interpreted as follows: A person that possesses knowledge by acquaintance has detailed knowledge of the properties of nanoscale silver particles and is familiar with their behaviour and reactions to and with other elements. This assumes that the knower is fully skilled and has personally acquired hands-on knowledge by simply dealing with nanosilver particles. The knowledge framework, however, makes no assumptions about the knower’s ability to go beyond what it known to him/her. That is, for instance, knowledge that is outside of the domain of the knower, such as the environmental impacts of nanoscale silver particles. In the context of policy knowledge, a person involved in policy-making has usable knowledge and information for policy-specific purposes. This should consist of knowledge about, in the context of nanoscale silver, the existence of nanoscale silver, the current use in products and manufacturing processes and, ideally, the potential health and/or environmental risks associated with the use of nanosilver (especially when the policy-choice outcome is to be legislation). At the same time, the knowledge framework would not expect the holder of relevant policy knowledge to also have detailed knowledge of properties of nanoscale silver particles; their behaviour and reactions of other elements. The framework should be read in a similar fashion with regards to the other three knowledge types. Table 5 should be used as an illustration only, in order to highlight key aspects of each of the different knowledge types. Detailed explanations for each of the knowledge types are provided in the sections 6.2.1 - 5.

As part of the analysis (chapter 6), the framework will be used to evaluate a number of policy recommendation, that are the result of intensive qualitative studies undertaken by Nanologue (2006). The aim is to use the knowledge framework and analyse policy recommendations and recommended actions with regards to their viability when viewed from the perspective taken up in this thesis that both information and knowledge are topics that are too complex to be viewed generally. Therefore, the knowledge framework can be used to analyse whether policy recommendations, for instance, are as useful and plausible when viewed from a knowledge specific perspective. For instance, a recommendation with regards to nanotechnology could be information sharing between the producers of nanotechnology-related knowledge and information and the public (and policy-makers). However, since information sharing is a very generalised statement, the framework will allow identification of what knowledge and information could be shared in terms of its usefulness to the intended recipient. A research publication on the toxicity of nanosilver particles is, in the majority of the cases, of no practical use to either the public or policy makers. Instead, such information would need to be tailored to the targeted recipient group. From a policy-recommendation perspective, any suggestions in this regard should therefore also specify what can be known by whom and how the information transfer has to happen. Chapter 6.3 will particularly discuss these issues.

The final aim of the knowledge framework is also to assess some of the previously introduced theories of the policy process with regards to information, knowledge and uncertainty. Ostrom (1990, 1991) uses the term information with regards to the information processing capabilities of actors. Moe (1995) uses knowledge, uncertainty and expertise dependency as key component of his framework. For Sabatier, information is a key component of his framework. However, considering the different types of information and knowledge that have extensively been discussed in this thesis, questions arise whether any of these authors refer to the terms information, knowledge and expertise in a rather generic way and whether, when viewed through the eyes of the knowledge framework, these theories can still hold their claims or whether the use of the terms information, knowledge and expertise in these theories needs to limited to very specific types.

3.7 Summary

This chapter discussed extensively the definitions of terms and concept such as data, information, knowledge, and expertise as well as knowledge by acquaintance and knowledge by description, tacit knowledge and explicit knowledge, and expertise. As this exercise has shown, terms such as data, information, knowledge and expertise should not be used generally, and most importantly, should not be used as a substitute for one another. Although, according to Rowley (1998), everyone should know what information is, the concept is actually ill-defined and, thus, needs to viewed context specific. For Lyre (2002) information is only what is understood, and information is only what also generates information. Put in a practical context, this can be interpreted as providing information (as in, providing content) and informing someone is not the same: *Information is meant to change the way the receiver perceives something …"* (Davenport & Prusak, 2000, p. 3). This is not only important within a business context, but also when it comes to the societal role which information plays, for instance, when it comes to either informing the public or to how the public informs itself. Similarly, the use of information in policy-making is generally accepted as vital, yet, as this chapter has shown, the term information cannot be used generically when it comes to policy making. Knowledge and information in policy contexts need to be usable.

Knowledge, as it has been illustrated, is an historic and complex concept. It is, therefore, not surprising that there is no single definition describing what knowledge is. Instead, there are vast amounts of differing and, often, competing concepts. Nevertheless, most relevant for the following two chapters (Chapter 4 and Chapter 5) are concepts involving know-what, know-why, know-how and know-who, knowledge by acquaintance and knowledge by description as well as the concepts of tacit and explicit knowledge. The latter, which is knowledge by acquaintance/description and tacit/explicit knowledge allow for making a distinction between what first-hand knowledge and what second hand knowledge is. As it has been shown, this is vital in order to differentiate between what can be known by whom, thus combining it with the concepts of know-what, know-why, know-how and know-who. What is more, expert knowledge (which is also domain specific knowledge) can, in a practical context, be equated with knowledge by acquaintance and/or tacit knowledge. Due to the specificity of expert knowledge, however, it needs to be highlighted that this equation does not work the other way around. In other words, not all knowledge by acquaintance and/or tacit knowledge is, at the same time, expert knowledge. This is not only due to the 10-year rule of necessary preparation that that is required to become an expert (Gruber, 2001), but also determined by the intent of the knower. For instance, an individual can purposefully acquire knowledge without having the intent of becoming an expert, for instance, learning how to use and operate an electron microscope does not make someone an expert in microscopy. Another reason why tacit/expert knowledge is important is because of its hidden nature; being unable to transfer this knowledge means not having (public) access to it. Again, this has a bearing on policy-making, as it invariably complicates the use of experts in decision-making processes. Although someone can be an expert in nanotechnology, it does not automatically make this person a suitable actor in policy-making. As it has been shown, the reasons for this are twofold: on the one hand, the expert in question may not have the necessary skills to 'get his/her expertise across'. On the other hand, having expertise in nanotechnology may not be of particular use to actors involved in making nanotechnology-related policy decisions, as, for instance, what they are looking for is an expert of nanotechnology related risk. These two areas may be complementary, but they are not the same; and the holder of one of these areas of expertise may not automatically also be a holder of the other. In order to overcome the problem, one must first identify which types can, and which types cannot, be transferred. If the former is due to the lack of incentives, then it can be transferred into explicit knowledge and information, no matter the complexity.

However, there is also a value to indirect knowledge; that is, knowledge that does not need to be acquired directly, such as knowledge by description or explicit knowledge. Here, the advantage is that it can be absorbed easily and is often sufficient for the receiver of that knowledge. The problem, similar to the concept of free information as discussed by Keohane and Nye (1998), is that it is up to receiver, which could be actors involved is policy-making, to verify that the knowledge is also reliable. If governments launch an information campaign on the dangers of smoking, for instance, then it is believed by the public that the information provided is also correct. This mode of knowledge or information dissemination is called the authoritarian mode (Frankfort-Nachmias & Nachmias, 2002). In these instances, people trust knowledge that has been provided by people, or organisations, that are regarded as ‘qualified producers’ of knowledge. This assumption can potentially bear enormous risks when dealing with complex subject matters, such as nanotechnology.

From a hands-on policy perspective, information, knowledge and expertise are of vital importance, as Meehan pointed out, “*[a] policy provides a solution to a choice problem; the problem is always analytically prior to the policy* (Meehan, 1993, p. 58). In order to come to a solution to such a choice problem, the use of policy information has an impact on the outcome. Thus, different uses of policy information also lead to different outcomes. As Oh and Rich (1996) have shown, decision makers approach the use of policy information depending on their familiarity with the problem, which in turn, also impacts the outcome. Furthermore, and especially in regard to complex subject matters (with which policy makers are unfamiliar), policy information and knowledge needs to be useful (Haas P. M., 2004) to the decision-maker.

> By demanding knowledge that is adequate for their purposes, the policymakers have the potential to channel and direct the quest for knowledge, and to modify the criteria used to assess and evaluate knowledge claims (Meehan, 1993, p. 55).

It has also been shown that, from a theoretical perspective, especially when looking at theories of the policy process, information – the term used by most theorists – and knowledge play a key role. While Ostrom (1990, 1991) uses the term information to describe information-processing capacities of actors, Moe (1994) uses knowledge and expertise dependency as a key component in his framework. Information also plays a key role in Sabatier’s framework of advocacy coalitions. This leaves questions with regards to the usage of the terms information, knowledge and expertise. These will be answered in Chapter 6 by means of using the knowledge framework, which has been established in this chapter. The knowledge framework is a matrix for comparing different types of knowledge and information, which have been established in this chapter, with the aim of applying these findings against data, in particular, technical data about nanotechnology and results and recommendations of intensive qualitative surveys undertaken by Nanologue (2006).

4. Nanotechnology

> While nanotechnology holds enormous potential, public understanding of what the technology does is actually as miniscule as the atoms it manipulates (Deloitte, 2008, p. 10).

Nanotechnology has been chosen as an example of a knowledge-intensive and expertise-dependent subject matter. This chapter will show that nanotechnology is one of the most recent areas of research that promises to be a game-changer with regards to current technological development. No other recent technology currently receives as much attention as well as funding as nanotechnology currently does. Yet, at the same time, little is known about nanotechnology by the general public. The same can be said about the social and/or environmental risks. Therefore, nanotechnology is an ideal area to be researched for the purposes on this thesis, as it will be shown that the knowledge requirements for this particular technology are extremely high, which in turn, poses challenges for both the public and policy making.

Following the general introduction below, various definitions are introduced and discussed. Subsequently, the importance of nanotechnology is examined and general trends of nanotechnology development are considered. Due to its novelty and its complexities, public reactions towards nanotechnology play an important role in the future of nanotechnology development, and are therefore highlighted here as well. This is followed by the introduction of one already known example of nanotechnological development that potentially bears a risk to health and environment, nanosilver, before summarising the findings and concluding this chapter.

This chapter will introduce the subject very generically, before then drilling down into technology related risks, which required a more science-based approach. A small example case is utilised to illustrate particular risks, or better said, potential risks by all accounts of contemporary understanding of nanotechnology risks. Here, nanosilver has been selected, as it provides insights that are particularly useful when applying the knowledge framework to nanotechnology. However, the discussions about nanotechnology have been purposefully kept at a descriptive level in order to ensure that any non-expert reader can follow. Thus, pure science-based research has been limited to an extent that on the one hand, the required information for this thesis can still be provided, while at the same time, omitting scientific data, such as details about test results. This applies especially to the study of Babu *et al.* (2008), which was particularly useful when investigating and comparing various knowledge types as part of the knowledge framework analysis. In addition, the nanotechnology discussion has been intentionally been kept as broad as possible. This has been done on purpose, as there is not enough data available yet to support such an effort.

4.1 Introduction

There has been much written about nanotechnology in recent years, albeit the most commonly known examples of nanotechnology can still be found in the realm of science fiction. The hugely popular franchises of Star Trek™ and Stargate™ dedicate entire subplots to nanotechnology. While Star Trek™ mainly explored the use of nano-bots; Stargate™ focuses on 'replicators', self-replicating, nano-technological, sentient (machine) beings. Popular science fiction authors covering the topic include Charles Stross (2003, Singularity Sky), Neill Stephenson (1995, The Diamond Age) and most notably Michael Crichton (2003, Prey).

In the real world, nanotechnology has become a buzzword, not only for the industry but also for policy-makers. An international nanotechnology business directory claims that "*[n]anotechnology is making its way into products and materials at a breathtaking rate, with about $2.6 trillion worth of goods worldwide expected to use nanotechnology by 2014, a 5,200 percent increase from just $50 billion in 2006*." (Nanovip, 2008), yet nanotechnology remains barely regulated. Considering that currently 3-4 new consumer products based on nanotechnology enter the market every week, the lack of specific regulation for a technology as unknown as nanotechnology seems to be a risk (PEN, 2008). Furthermore, considering how little is known about nanotechnology in general and how little is known about nanotechnology by the public, this will undoubtedly have consequences. These consequences may range from (negative) reactions to bringing products to market if the public was not aware of either its contents or production methods to consequences that would arise in the case of an environmental or health-related incident with grave negative impacts. Especially the latter would take both politicians and the public by surprise when they had not been warned of the risks, dangers and consequences of nanotechnology. In many cases, if there were a nanotechnology-related environmental incident, for instance, in the next few years, the public would very likely feel being part of the aforementioned science-fiction novels.

4.2 What is nanotechnology?

It is commonly accepted that Richard Feynman introduced the concept of nanotechnology in 1959, without, however, using the term nanotechnology.[23] Feynman (1959) discussed a process allowing the manipulation of atoms and molecules by means of developing a set of tools that would provide for building another, smaller, set of tools until the needed scale has been reached. Outside the world of science fiction, K. Eric Drexler (1986) propelled the term nanotechnology into (relative) common use, albeit his introduction of the term 'grey goo' painted a rather negative, if not sensation seeking and disastrous picture. The complexities inherent in nanotechnology shall be illustrated by means of the four varying definitions below:

> The prefix *nano* in the word nanotechnology means a billionth ($1x10^{-9}$). Nanotechnology deals with various structures of matter having dimensions of the orders of a billionth of a meter (Poole & Ownes, 2003, p. 1).

> Nanotechnology literally means any technology performed on a nanoscale that has applications in the real world. Nanotechnology encompasses the production and application of physical, chemical, and biological systems at scales ranging from individual atoms or molecules to submicron dimensions, as well as the integration of the resulting nanostructures into larger systems (Bhushan 2004, p. 1).

> As the name implies, nanotechnology involves the engineering or manipulation of matter, and life, at nanometer scale, that is, one-billionth of a meter. (Ten hydrogen atoms side by side span 1 nanometer; the DNA molecule is 2.3 nanometers across) (Hook, 2004, p. 1871).

[23] The term nanotechnology was first introduced by Norio Taniguchi in 1974.

> … the word “nanotechnology” will be associated with human-designed working devices in which some essential element or elements, produced in a controlled fashion, have sizes of 0.1 nm to thousands of nanometres, … (Wolf, 2004, p. 1).

The first definition clearly defines the key to understanding nanotechnology: size[24]. The second and the third definitions, however, stress the element of human interaction through engineering, application, and manipulation. What is more, both definitions include the physical as well as the biological dimensions, whereby the first definition remains vague when it comes to the ‘hows’ and ‘whats’. The fourth definition focuses on devices that are being produced, despite the author’s awareness that before that can happen, a major (nano-) technological breakthrough is required. This shows that nanotechnology has not been fully defined yet, as the focus of a given definition often only highlights one or two typical characteristics, depending on the authors’ background or point of view. One potential reason for this is provided by Wolf (2004):

> The reader may correctly infer that Nanotechnology is presently more concept than fact, although it is certainly a media and funding reality. That the concept has great potential for technology, is the message to read from the funding and media attention to the topic (Wolf, 2004, p. 1).

In stark contrast to this lies Drexler’s initial understanding of nanotechnology. His focus is on nano-assemblers, self-replicating machines that once built, will continue developing machines and tools at nano-scales (Drexler, 1986). Nowadays, this branch is mostly referred to as molecular nanotechnology. Since it is unlikely that this type of technology will be available for quite some time (see overview of generations nanotechnology in Figure 1), further clarification is required on the definition and on the use of the term nanotechnology in science today. The Centre for Responsible Nanotechnology defines it as follows:

[24] “The British Standards Institution (BSI) defines the nanoscale as between 1–100 nm. A nano material is defined by BSI as having one or more external dimension in the nanoscale (BSI, 2007). A nano object is a discrete piece of material with one or more external dimensions in the nanoscale. A nanoparticle is a nano object with all three external dimensions in the nanoscale. A manufactured nanoparticle is a solid entity with size from approximately 1nm to 100 nm in at least two dimensions that has been produced by a manufacturing process” (Luoma, 2008, p. 10)

> **Nanotechnology is the engineering of functional systems at the molecular scale.** This covers both current work and concepts that are more advanced. In its original sense, 'nanotechnology' refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products (CRN).

Furthermore, the Centre argues that “[m]*uch of the work being done today that carries the name 'nanotechnology' is not nanotechnology in the original meaning of the word.”* (CRN). Their reasoning behind this statement is based on potential risks, therefore a distinction is being made between nanotechnology as defined above and what nanotechnology is not: *“As used today, the term nanotechnology usually refers to a broad collection of mostly disconnected fields. Essentially, anything sufficiently small and interesting can be called nanotechnology. Much of it is harmless”* (CRN). What is interesting here is the fact that CRN’s definition of nanotechnology also omits the range of self-replication nano-assemblers. This follows Wolf’s (2004) assumption that a major breakthrough (the so-called nano-assembler breakthrough) is required first. Where Wolf is wrong, or better still, outdated (his book was published in 2004), is in his assumption that nanotechnology is more concept than fact. This also shows the pace with which nanotechnology progresses and adds to the urgent need of a better understanding of nanotechnology. The following table provides an abbreviated overview of the system of units and some examples in order to get a better understanding of the size with which nanotechnology deals:

10^n	Prefix	Name	Expressed in decimals	Example	Size
10^{12}	tera-	Trillion	1 000 000 000 000		
10^{9}	giga-	Billion	1 000 000 000		
10^{6}	mega-	Million	1 000 000		
10^{3}	kilo-	Thousand	1 000		
10^{2}	hecto-	Hundred	100		
10^{1}	deca-	Ten	10		
10^{0}	(none)	One	1		
10^{-1}	deci-	Tenth	0.1		
10^{-2}	centi-	Hundredth	0.01		
10^{-3}	milli-	Thousandth	0.001	ant	ca. 5 mm
10^{-6}	micro-	Millionth	0.000 001	blood cell	ca. 2-5 µm
10^{-9}	nano-	Billionth	0.000 000 001	DNA	ca. 2-12 nm
10^{-12}	pico-	Trillionth	0.000 000 000 001		

Table 6: Overview of unit sizes

A number of selected nanotechnological applications expected to emerge (see also Chapter 4.4) are summarised in the table below.

Area	Expected applications
Environmental	Remediate contaminated soil and water Reduce use of raw materials through improvements in manufacturing Rebuild the stratospheric ozone layer with the assistance of nanobots
Medical	Improve the delivery of drugs Develop techniques in nanosurgery Repair defective DNA Improve diagnostic procedures
Electronic	Develop molecular circuit boards Improve storage of data Develop molecular computers
Materials	Increase the strength of industrially valuable fibres Replicate valuable products Improve the quality and reliability of metals and plastics Manufacture “smart” materials

Table 7: A sample of applications expected to emerge from Advances in Nanoscience (Mehta, 2002, p. 270)

There is yet another side that needs to be explored in addition to technological approaches to the topic. Poole and Owens (2003) argue that in addition to nanomaterials that are based on chemical elements, there are also natural building blocks, such as proteins, and also viruses that need to be taken into account. They argue that since nanomaterials and nanostructures are defined by sizes between 1 and 100 nanometres, viruses ranging between 10 and 200 nanometre fall into the upper part of the nanoscale range. Proteins ranging in size between 4 and 50 nanometres fall into the lower part of the nanoscale. In comparison, and to clarify, bacteria have sizes between 1 and 10 micrometres and therefore do not fall into the group of nano materials or structures. The following table will give an overview of typical sizes of various biological substances:

Class	Material	Size (in nanometre)
Amino acids	Glycine (smallest amino acid)	0.42
	Tryptophan (largest amino acid)	0.67
Nucleotides	Cytosine monophosphate (smallest DNA nucleotide)	0.82
	Guanine monophosphate (largest DNA nucleotide)	0.86
Other molecules	Chlorophyll, in plants	1.11
Proteins	Insulin, polypeptide hormone	2.2
	Haemoglobin, carries oxygen	7.0
	Lipoprotein, carrier of cholesterol	20
	Fibrinogen, for blood clotting	70
Viruses	Influenza	60
	Tobacco mosaic length	120
	Bacteriophage T2	140

Table 8: Typical sizes of various biological substances in the nanometre range (Poole & Ownes, 2003, p. 315) - abbreviated overview

Finally, the following figure shows a timeline of predicted nano-technological developments in the next 10-20 years. What immediately becomes obvious is that the timeline goes only as far as to speak of molecular nano-systems and also omits self-replicating nano-assemblers. Thus, for the purposes of this research, it should be assumed that nanotechnology, nanomaterials and nanostructures exclude self-replicating assembly at a nanoscale for years to come.

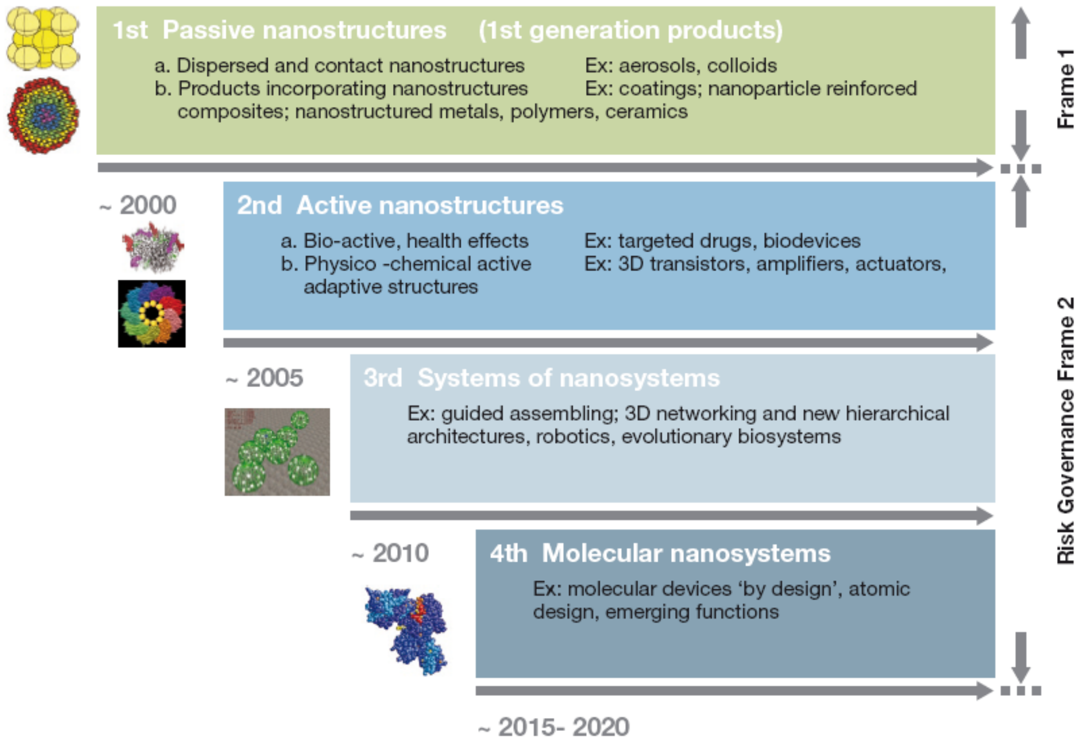

Figure 4: Timeline for Beginning of Industrial Prototyping and Nanotechnology Commercialisation: Four Generations of Products and Production Processes (IRGC 2006, p.23)

4.3 Why is nanotechnology important?

First off, this is important from an economic perspective. "*Nanotechnology is an area which has highly promising prospects for turning fundamental research into successful innovations. Not only to boost the competitiveness of our industry but also to create new products that will make positive changes in the lives of our citizens, be it in medicine, environment, electronics or any other field*" (Commission, 2005, p. 1). Although the funding itself has increased to staggering amounts of Dollar, Euro, Yen *et cetera*, which in itself creates and secures current jobs, the long term benefits of current funding initiatives have to be seen in economic dominance secured by both patenting and manufacturing capabilities. Even before globalisation became a buzzword, a number of nations had to learn tough lessons about foreign competition. As nanotechnology is practically a new technology that is currently regarded as key to the future, a future that also always includes a future of economic wellbeing and wealth, many of the current funding champions are interested in nanotechnology because they want to be part of that economically wealthy future. Then, there is politico-scientific dominance; that is, the dominance of global powers in the areas of key technologies. Certainly of major importance are prospective uses of nanotechnology in military applications. For instance, this could include new materials that make current military hardware more secure and/or longer lasting, applications that increase the security of military personnel and soldiers even in combat situations, or it could include applications that help to clean up combat zones. On the other hand, nanotechnology also holds large potential for uses in new, nano-based offensive weaponry (if that is desired) and bears enormous risks of abuse due to its size, probable mobile deployment capabilities and, if desired, time-delayed release mechanisms. In addition, there are a number of materials that are in their common form/composition harmless, yet when in nano-particle state they turn harmful, even toxic.

> That is deeply troubling to many scientists, because the same amazing properties that make nanotech materials and devices so promising also create the potential to do unexpected harm, particularly when they enter the human body. For example, nanotech materials are so small that some might be able to pass by the body's defences, including the walls of cells. Since nanotech materials have an exponentially greater amount of atoms on their surface areas than their full-sized cousins, a substance that is perfectly safe in its regular form could turn out to be toxic in its nanotech form (Nanovip, 2008).

In politics, nanotechnology has only recently gained broader popularity. The result of this, however, was an immediate increase in public funding. Between 1997 and 2003, worldwide funding has increased by 700 percent, whereby funding in countries other than the USA, Japan and Western Europe increased by 1143 percent[25] in the same time period (Rocco 2003). In comparison, federal funding in Germany pales beside that of the US, although no European government spends as much on nanotechnology as Germany. The table below provides a comparison of nanotechnology funding between the USA, Germany and the EU's framework programmes:

[25] Own calculation based on Rocco (2003).

Year	USA	Germany	EU
2001	$465	€ 210	
2002	$697	€ 240	€1.300 (6th Framework Programme)
2003	$774	€ 258	
2004	$849	€ 273	
2005		€ 310	
2006		€ 330	
2007		€ 330	€3.475 (7th Framework Programme)
2008	+$2.000[26]		
2009			
2010			
2011			
2012			
2013			

Table 9: Nanotechnology funding (in million) based on Rocco (2003) and BMBF (2006)

In the US, the political interest in nanotechnology was effectively demonstrated in the 2006 State of the Union address, where former US President George W. Bush mentioned nanotechnology for the first time: "*First, I propose to double the federal commitment to the most critical basic research programs in the physical sciences over the next 10 years. This funding will support the work of America's most creative minds as they explore promising areas such as nanotechnology, supercomputing, and alternative energy sources*" (The White House, 2006). In 2003, the US '21st Century Nanotechnology Research and Development Act' was signed, dedicating $849 million for nanotechnology R&D across 10 federal agencies. That amounted to a 10% increase on nanotechnology spending in comparison to 2003. Between 2001 and 2004, nanotechnology spending in the US had risen by 83 %. In 2008, the US budget made the following provisions:

> National Nanotechnology Initiative: $1.45 billion, a 4.2 percent increase, to continue to support discovery, development and application of nanotechnology through investigator-led fundamental and applied research; multidisciplinary centers of excellence; education and training of nanotechnology researchers, teachers, workers, and the public; and infrastructure development, including

[26] Own estimates based on the 2008 budget.

user facilities and networks that are broadly available to support research and innovation (The White House, 2008, pp. 41-42).

The Department of Commerce's National Institute of Standards and Technology: $594 million, to enhance nanotechnology manufacturing capabilities; expand a neutron facility to help characterize novel materials; construct new, high-performance laboratories; and improve our understanding of quantum information science that may dramatically improve computer processing speeds and enable more secure communications. (The White House, 2008, pp. 34, 42).

Additionally, a large proportion of the $6.4 billion budget of the National Science Foundation will go towards addressing "*specific priorities in … nanotechnology…"* (The White House, 2008, p. 33).

In addition to the EU's funding initiative, and funding by other major European powers, other countries followed suit. In August 2007, the Russian government approved the following nanotechnology programme: "*Development of the Infrastructure of the Nanotechnology Industry in the Russian Federation 2008-2010*", worth 27.773 billion Roubles (ca. 1.134 billion US Dollar/766 million Euro) (Kommersant, 2007). Israel also has launched a National Nanotechnology Initiative, spending US $230 million between 2007 and 2011 (INNI, 2006). Based on recent developments, other states will follow suit and launch similar national nanotechnology initiatives. Slightly different figures are shown by Lux Research for the year 2006. What is interesting here is the fact that corporate spending nearly matches government spending, thus contributing to an overall serious investment. Only one year later, in 2007, corporate spending on nanotechnology had already exceeded government funding with US $6.6 billion (Nanotechwire, 2008) and total funding increased to US $13.5 billion (Lux Research, 2007).

Another reason for the importance of nanotechnology can be found by looking at its potential risks (see also Chapters 4.4 and 4.5). Going forward, serious research will be required to determine both health and environmental aspects of nanotechnology.

Behra and Krug highlight that the majority of toxicity studies that have been carried out have focused on human health. Until now, environmental aspects are mostly unexplored and require urgent attention. "*Some studies have shown that fullerenes, carbon nanotubes and various metal and metal oxide nanoparticles can affect the physiology of different aquatic organisms such as fish, algae and water fleas*" (Behra & Krug, 2008, p. 253). The authors mention that nanotechnology experts in areas of exposure, behaviour, analysis, nanoecotoxicology and green nanotechnology agree that there is a need for further research "*in a range of areas — such as detection and characterization, environmental fate and transport, ecotoxicology, and toxicology — is needed to solve the issues at hand and to gain a mutual understanding of the concerns and requirements*" (Behra & Krug, 2008, p. 253). Thus, the political importance of nanotechnology stems not only from its potential use in military applications of major powers; it must also be regarded as a security concern of the same.

Finally, in addition to the economic, political, military/security, and environmental/ health aspects that nanotechnology will impact in the long term, there is also a personal aspect, that of individual citizens and consumers. As the case of GMO, in particular, the issue around the need for labelling of GMO products or additives to products, has shown, there are instances when the public wishes to know about what is in their products. Until now, all products that have either been produced by using nanotechnology or contain nano-particles are being sold without labelling that indicates nanotechnology. Quite the contrary, nanotechnology has been used as marketing vehicle in order to better sell products. This, of course, can only go on for a certain period of time. In only one or two generations, nanotechnology will have reached a stage where 'more serious products' are ready for market. What then?

4.4 Current developments and trends

One can expect nanotechnology to become the 'new biotechnology', an area that is not only perceived by many as the next technological leap, but an 'idea' that promises to solve the worlds' illnesses, such as disease, hunger, pollution *et cetera*. Kahan *et al.* summarise the benefits of nanotechnology as follows: "*Its immense range of potential applications—scientific, commercial, medical, and more—marks nanotechnology as* *one of the most promising new forms of applied science*" (Kahan, Braman, Slovic, Gastil, & Cohen, 2008, p. 1). Also similar to biotechnology, nanotechnology is an exceptionally complex subject matter. This alone may account for the 'myth building' element that both biotechnology and nanotechnology inherit. There are a number of benefits that are being attributed to nanotechnology; that is, in addition to the predicted US $1.3 trillion worldwide market by 2015. One of the most popular assumed benefits of nanotechnology is environmental protection, or, to be precise, the use of nanotechnology to clean polluted water and soil. But also medicine is a often used example, where, for instance, nanobots could potentially repair damaged cells. This example might be quite far off into the future; a more immediate possibility is the use of nanotechnology in the development of better drug delivery systems. The 2003 report of the British Foundation for Science and Technology listed the following:

Already available products:

- Hard disks – devices based on giant magnetoresistance in nanostructured magnetic multilayers dominate the market
- Sun-block creams based on nanoparticles that absorb UV light
- Lasers, modulators and amplifiers for telecommunications

Products and applications close to market introduction include:

- Better photovoltaic techniques for renewable energy sources
- Glasses with scratch resistant coating
- Harder, lighter and stronger materials
- 'Lab-on-a-chip' diagnostic technologies
- Quantum structure electronic devices
- Self-cleaning surfaces
- Advanced photonics devices in telecommunications (FST, 2003, p. 2)

In 2007, the list of available products that either contained nanoparticles or were based on nano-technological production mechanisms contained (Dabek, 2006; Nanowerk, 2007):

- Golf balls, tennis racquets and coated fishing lures
- Stain-resistant khaki trousers and ties
- Shoe inserts and socks
- Lip gloss, skin cream and men's razors
- Household paint
- Wrinkle-free fabrics
- Toothpaste

This list is to grow in the near future; it very probable that this list might even grow dramatically. The striking element here is that nearly all of these products are day-to-day use household products, with many of their users being not aware of the nanotechnology linkage.

However, when considering the advances corporations have made with regards to nanotechnology-related products, then this does not come at a surprise. Figure 5 (see figure below) provides an overview of the top 10 institutions in the EU, Japan and the US based on nanotechnology patents. Corporations account for twenty of the thirty listed institutions; the remaining ten are a mix of universities and other public institutes. This was not unexpected when considering the increase in corporate nanotechnology funding. Between 2006 and 2007, the number of manufacturer-identified nanotech goods listed by the online Project on Emerging Nanotechnologies had "*increased 175 percent--from 220 to 580 products. There are 356 products in the health and fitness category--the inventory's largest category--and 66 products in the food and beverage category. One of the largest subcategories is cosmetics with 89 products*" (PEN, 2007) A rather large number of products are based on the use of silver nanoparticles: "*The nanomaterial of choice appears to be silver--which manufacturers claim is in 139 products or nearly 25 percent of inventory--far outstripping carbon, gold, or silica*" (PEN, 2007).

The future of nanotechnology will not just depend on availability of funding or on technological breakthroughs alone. It will also depend on the public perception of nanotechnology.

Rank	Institution	No. of patents
	US Patent and Trademark Office	
1	IBM	209
2	University of California	184
3	US Navy	99
4	Eastman Kodak	90
5	Massachusetts Institute of Technology	76
6	Micron technology	75
7	Hewlett-Packard	67
8	Xerox Corporation	62
9	3M Company	59
10	Rice University	51
	European Patent Office	
1	Japan Science and Technology Agency (Japan)	78
2	L'Oreal (France)	60
3	IBM (US)	50
4	Rohm & Haas (US)	47
5	Samsung (South Korea)	45
6	Eastman Kodak (US)	40
7	CEA (France)	39
8	CNRS (France)	37
9	Matsushita Electric Industrial (Japan)	32
10	BASF (Germany)	31
	Japan Patent Office	
1	Nippon Electric	109
2	Japan Science and Technology Agency	70
3	National Institute for Materials Science	52
4	National Institute of Advanced Industrial Science	48
5	Matsushita Electric Industrial	45
6	The Agency of Industrial Science and Technology	43
7	Tokyo Shibaura Electric	43
8	Sony	32
9	Canon	31
10	Seiko Instruments	27

Figure 5: Top 10 institutions based on European, US and Japanese patent offices (Chen, Rocco, Li, & Lin, 2008)

4.5 Public reactions to and understanding of nanotechnology

There have been a number of studies towards the publics' perception of nanotechnology. Some focussed on available knowledge; that is, what does the public know about nanotechnology, some focussed on the perception of risk and others focussed on moral questions. Why is public perception important? Currall *et al.* stress that "*[u]nderstanding public sentiment towards nanotechnology is pivotal because, historically, public perceptions and attitudes have shaped the direction and pace of* *scientific activity in a number of fields. This has been and continues to be the case with nuclear power, genetically modified organisms (GMO), embryonic stem-cell research and biotechnology. In the case of GMO, negative public sentiment has had an adverse effect on governmental funding of research, especially in Europe*" (Currall, King, Lane, Madera, & Turner, 2006, p. 153). The following sheds some light on the outcomes of these studies and on possible lessons learned and/or future implications.

A group of researchers around Dan M. Kahan at Yale Law School conducted a number of polls to gauge the public's reaction towards nanotechnology. In general, they argue, that "*[n]ot much more is known about public perceptions of the risks of nanotechnology than is known about nanotechnology risks themselves*" (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 4). In their first study, the main hypothesis was "*that individuals' perceptions of nanotechnology risks and benefits would be affect driven*" (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 9); that is, not driven by information, and/or knowledge, or, simply put, facts but by what 'people feel', based on existing values. A sub-hypothesis of the study was that the affect can be explained by people's disposition towards environmental risks. In addition, the authors also expected that people's affect would reflect their cultural disposition: "*We predicted, in particular, that hierarchical and individualist subjects would have a relatively positive affective response to nanotechnology, and egalitarian and communitarian subjects a relatively negative one, in accord with the dispositions of such persons toward environmental risks generally*" (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 10). This means that already existing values, to which people subscribe, such as being conservative, 'green' or liberal, pre-determined their responses and reactions towards nanotechnology and its risks. When asked if they have they heard about nanotechnology before, 53% of the asked sample[27] responded with 'no', and only 5% responded with 'a lot' (see Figure below).

[27] Sample size (n=1500), thus Kahan *et al* (2007) argue that the result can be projected towards the American public in general.

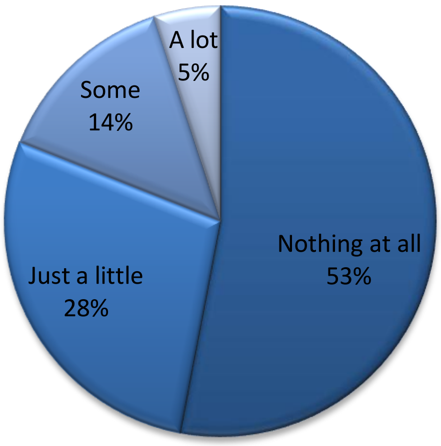

Figure 6: Prior knowledge of nanotechnology (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 15)

After being supplied with some information on nanotechnology, one group of participants were asked about the risks vs. benefits, and some 53% indicated either 'strongly' or 'slightly' that the benefits outweigh the risks (see figure below).

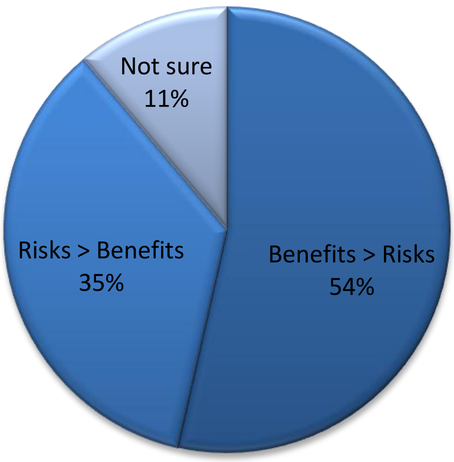

Figure 7: Risks vs. Benefits, No-Information Condition (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 16)

In comparison, a group that was asked the same risk-benefits question without, however, being supplied with information answered as follows:

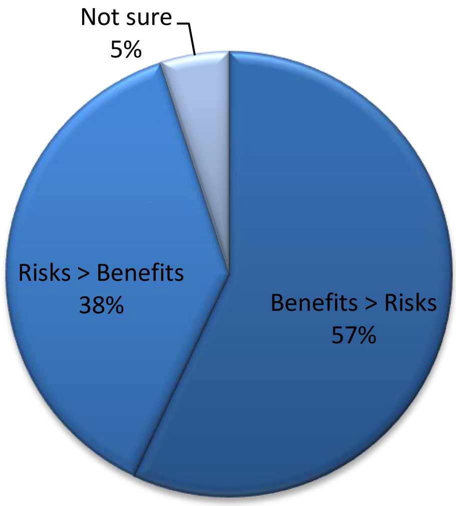

Figure 8: Views of Subjects Across Conditions (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 22)

When comparing the sample groups with (Figure 9) and without (Figure 10) prior knowledge of nanotechnology, it turned out that the risks vs. benefit ratios were relatively close and that additional information did not matter. Kahan *et al.* concluded that "*[t]he main effect of information exposure—that is, the overall effect of information exposure across the treatment groups—is essentially nil*" (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 22). However, the authors highlight that this is due to the fact that the majority of people in the group of individuals that had prior knowledge of nanotechnology indicated that they had only 'just a little knowledge'. In the same vein, one could argue that a little knowledge equals no knowledge. This is somewhat supported by the means analysis and the clearly visible gaps between 'information have's' and 'information have not's' and their attitude towards risk:

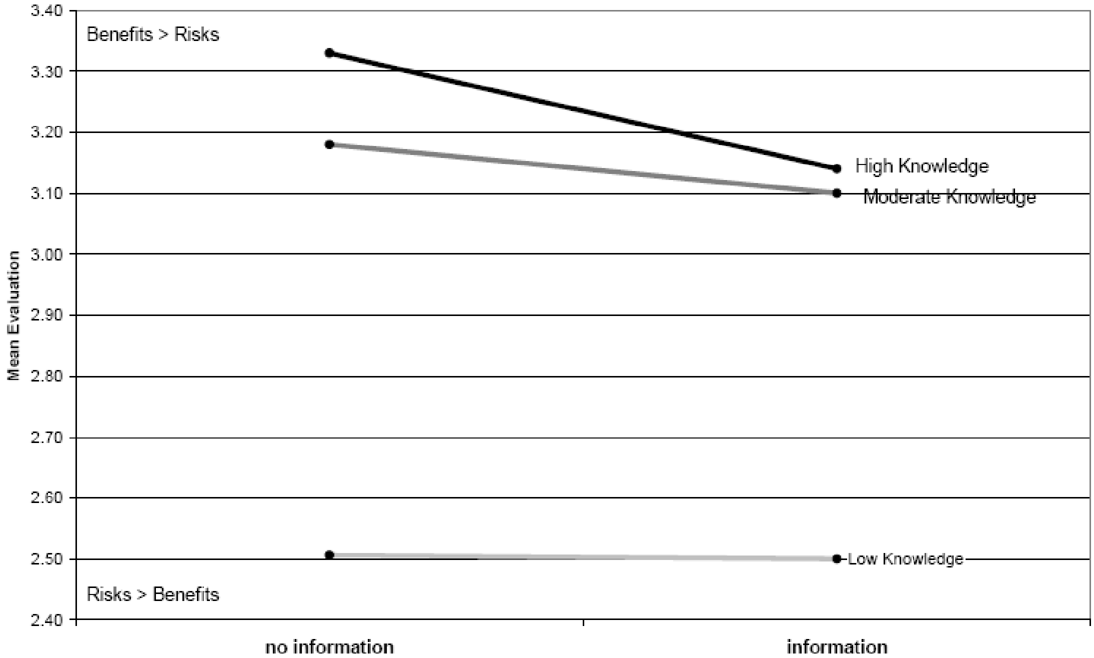

Figure 9: Impact of Information Across Condition by Prior Knowledge Level (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 30)

What shapes these opinions? Kahan *et al.* argue that the majority of opinions are formed affectively, that is, people form instantaneous opinions based on their 'gut feelings'; "*Indeed, we found that this emotional response to nanotechnology better explains differences in individuals' opinions than does any other factor, including their race or gender, their level of education, their income, their political and cultural commitments, their trust in government, and their level of knowledge about nanotechnology*" (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, pp. 30-31). This raises questions as to how people form their opinions and how they get their 'gut feelings'? As mentioned above, an associated aim of this study was to see if environmental values play a role in the perception of nanotechnology. The authors come to the conclusion that risk assessment is based on values. For instance, individuals whose values predispose them to give credit to claims of environmental risks are more alarmed than individuals whose values predispose them to dismiss claims of environmental risks. In layman's terms this means that people with an individual track record of being conscientious or aware of environmental risks in general are also very likely[28] to be more sceptical about environmental risks of nanotechnology and *vice versa*. Concluding, Kahan *et al.* say that there remains at least one general puzzle:

> There is clearly a positive correlation in general between how much people know—or at least report knowing—and the view that nanotechnology's benefits outweigh its risks. At first glance, this appears to imply that people become more favorably disposed to nanotechnology the more they know about it. But this interpretation is almost certainly incorrect, or at least unduly simplistic. As our own results demonstrate, people with different values react in divergent ways—some negatively, some positively—to the same information. In addition, considering only how much people knew prior to the study, exposing ill informed people to information did nothing to narrow the gap between their relatively negative view of nanotechnology and the relatively positive view of persons who describe themselves as well-informed (Kahan, Slovic, Braman, Gastil, & Cohen, 2007, p. 33).

The relationship between prior knowledge and positive view of nanotechnology seems to be deceptive, thus, the authors conclude that 'some other influence' makes people that have a positive disposition towards nanotechnology wanting learn more about it. What that 'other influence' is, the authors do not say. A second study carried out concluded that a "*strategy of public education that focuses only on disseminating accurate information cannot reliably be expected to generate convergence on accurate public beliefs about the risks and benefits of nanotechnology*" (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008, p. 2). Using qualified experts to deliver arguments about nanotechnology, and the risks and benefits associated with it, may not necessarily counteract cultural predispositions toward environmental and technological risks.

> Just as individuals often lack the time and capacity to assess the soundness of information on their own, they also often lack the time and capacity to assess the training and knowledge of information providers. Moreover, on almost any risk issue of significance—from global warming to domestic terrorism, from

[28] Kahan *et al* stress that there is no causality (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008).

> school shootings to vaccination of school-age girls for human papillomavirus—members of the public will be confronted with duelling advocates whose expert credentials (scientific training, university affiliations, and the like) are roughly comparable (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008, p. 14).

In their third and final study, Kahan *et al.* investigated the way forward with regards to public risk perceptions and nanotechnology. Is the aim of having a well-informed citizenry that can balance pro and counter arguments worth pursuing? Is there anything else that needs to be done in addition to 'simply informing' the public? The researchers conclude that "*[i]t would be a mistake, …, to assume that nothing more need be done than to supply people with scientifically sound information*" (Kahan, Braman, Slovic, Gastil, & Cohen, 2008, p. 19). This, as the authors stress, is due to ordinary citizens lacking both time and expertise to assess information (technical data) on risk properly, especially when it can be disputed. Instead, people tend to evaluate information based on their cultural disposition and preference. Therefore, risk is being evaluated in the same way, or as Kahan *et al.* put is: "*issues of risk tend to polarize on cultural lines*" (Kahan, Braman, Slovic, Gastil, & Cohen, 2008, p. 20); that is, information is evaluated by ordinary people in the same polarised fashion that shapes their opinion on any other matter.

Hence, one can argue that general cultural and political predisposition and orientation seem to be of greater importance than balanced technical information itself. This poses a danger to nanotechnology, and any other potential future technology that is highly dependent on expertise: they are faced with the potential of becoming culturally and politically dividing. "*Nanotechnology, on this view, could go the route of nuclear power and other controversial technologies, becoming a focal point of culturally infused political conflict*" (Kahan, Braman, Slovic, Gastil, & Cohen, 2008, p. 20). Even though this is not an inevitable future, Kahan *et al.* suggest that more research and effort is needed in the areas of risk communication so as to avoid polarisation as it has been seen previously, for instance, around nuclear energy or GMOs. This is also important if future public deliberations over nanotechnology are seen as desirable. As Kahan *et al.* have pointed out, for the time being, little information makes little difference.

A different kind of study was carried out by Currall *et al.* (2006). Here, the aim was to compare nanotechnology and its risks and benefits with those of other technologies, such as biotechnology, stem-cell research or GMOs (see Figure below). On the right hand side, the figures shows technologies that are associated with a high risks. These include material and elements, such as asbestos and mercury, and technologies, such as biotechnology and nuclear power. Technologies shown at the top, or close to it, are seen as providing the highest benefit. The results show that nanotechnology was seen as less risky than, for instance, biotechnology or GMOs. It also shows that the expected benefits are currently seen as being lower than that of biotechnology or solar power. This is not surprising when considering the fact that the public still does not know much about nanotechnology.

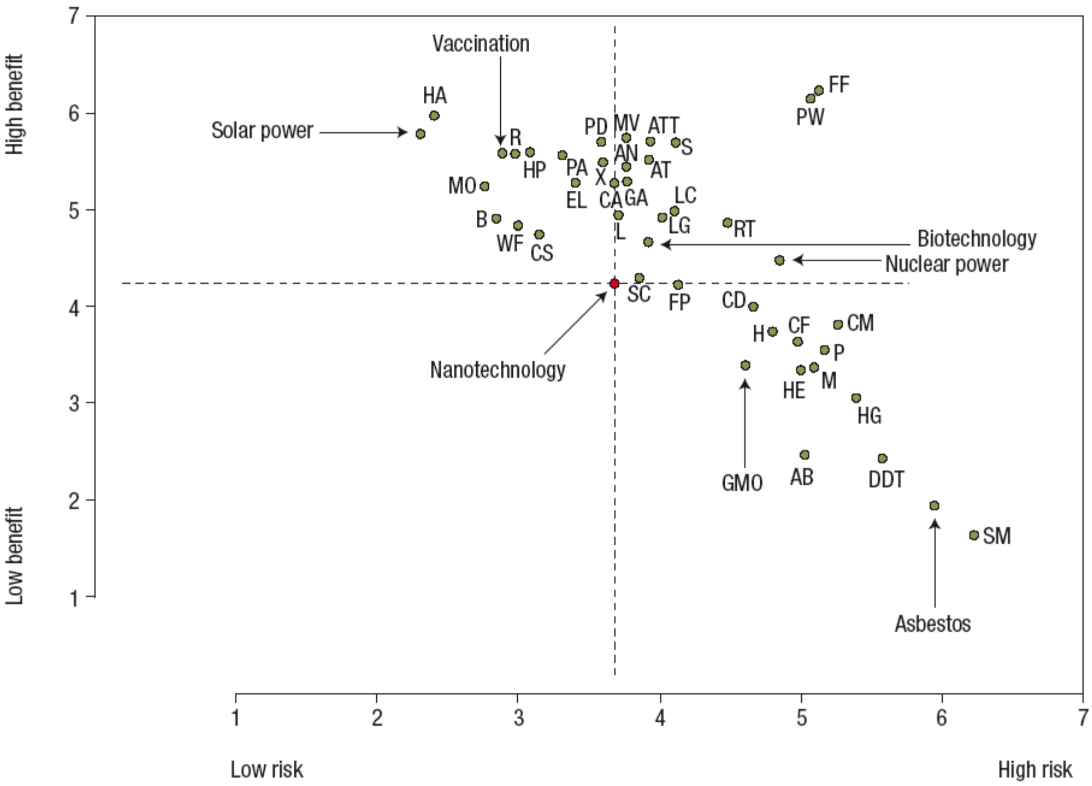

Figure 10: Perceived risks and benefits of nanotechnology[29] (Currall, King, Lane, Madera, & Turner, 2006, p. 154)

[29] The acronyms are: alcoholic beverages (AB), anaesthetics (AN), air travel (AT), automobile travel (ATT), bicycles (B), commercial aviation (CA), chemical disinfectants (CD), chemical fertilizers (CF), chemical manufacturing plants (CM), computer display screens (CS), dichloro-diphenyltrichloroethane

Currall concluded that "*current public sentiment towards nanotechnology is relatively neutral*" (Currall, 2007). Moreover, he suggests that "[b]*ased on our findings, we question an assumption by many of our science and engineering colleagues that the public thinks about nanotechnology applications only in terms of possible risks. To the contrary, our results showed that public perceptions of nanotechnology weren't as simple as previously assumed—risks and benefits are both enmeshed in a complex decision-making calculus*" (Currall, 2007). Thus, the public should be educated on the risks and benefits of nanotechnology in order to prevent nanotechnology encountering the same opposition as GMO. How this can be achieved is suggested as follows:

> With respect to the future, government funding should be provided for interdisciplinary research centres that promote collaborative research among physical scientists, engineers and social scientists. Additionally, social scientists should be encouraged, through research grant opportunities, to develop metrics and track the public's understanding of the risks and benefits of nanotechnology. For example, we have presented a research methodology that can be used as a scorecard for gauging how the public compares nanotechnology with other technologies. (Currall, King, Lane, Madera, & Turner, 2006, p. 155).

This is because the public engages in a trade-off between risks and benefits, as perceived levels of risks depend on the extent of the expected benefits and vice-versa (Currall, 2007). A survey carried out by Peter D. Hart Research Associates for the Project on Emerging Nanotechnologies in 2007 confirms that, at least in the US, "*simply telling people more about nanotechnology is not enough. Of 1,014 adults asked about the risks and benefits of nanotechnology, around half did not answer the question, which is not surprising given that almost three quarters had heard little or nothing about nanotechnology*" (Peter D. Hart Research Associates, 2008). This seems

(DDT), electric power (EL), fire fighting (FF), food preservatives (FP), general aviation (GA), herbicides (H), home appliances (HA), human genetic engineering (HE), handguns (HG), hydroelectric power (HP), lasers (L), large construction (LC), liquid natural gas (LG), motorcycles (M), microwave ovens (MO), motor vehicles (MV), pesticides (P), prescription antibiotics (PA), prescription drugs (PD), police work (PW), railroad (R), radiation therapy (RT), surgery (S), stem-cell research (SC), smoking (SM), water fluoridation (WF), X-rays (X). (Currall, King, Lane, Madera, & Turner, 2006, p. 154) to corroborate the findings of Kahan *et al.* (2007, 2008). "*However, when asked again, after being informed about the risks and benefits, the percentage who thought the benefits were greater than the risks increased from 18% to 30%, whereas those who felt the risks and benefits were similar rose from 25% to 30%. Disturbingly, however, the percentage who believed that the risks outweighed the benefits increased from just 6% to 22%*" (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008). This is somewhat different to the finding of other studies, because providing information did not automatically trigger people to become more concerned about it. And, to complicate matters further, differences in opinions have been identified when analysing the responses by gender, age, income and along political values (Kahan 2007, 2008).

4.6 The current understanding of the risks of nanotechnology

Considering the results of the observed public opinions towards the potential risk of nanotechnology, it seems to be crucial to get a better understanding of the risks, as seen by the science and technology community today. Therefore, the following identifies current trends with regard to known and/or suspected risks of nanotechnology.

The general perception is that there is little known about nanotechnology risks (Nanologue, 2005; Kahan *et al.*, 2008). This is not because nanotechnology is itself still a fairly recent development, but also because there are not many products available, at least when compared to the overall market. Another element that plays a role here is the complexity that is inherent in this type of technology/area of research. Moreover, nanotechnology research is not limited to publicly-funded and executed research, such as in universities and other government laboratories, but stretches also into the corporate realm. If the previously mentioned figures from Lux Research (2007) are anything to go by, then it seems that corporate funding has already exceeded public funding. In the same vein, funding through venture capital is also very likely to increase; therefore managing or overseeing current research has already become incredibly difficult. For instance, as of 2008, there are approximately 1200 nanotechnology firms in the US alone, yet more than 80 percent have fewer than 10 employees (CSP, 2008). This, first of all, makes global oversight of research and the associated risks impossible, and, secondly, national oversight needs to be regarded as already challenging. Before one spins this further, for instance, by adding the risks of nanotechnology related research being carried out in either less democratic countries or by rogue nations or groups, then a picture arises that might suggest an inevitable myriad of forthcoming challenges. Whether this is already the case or whether this remains a potential future scenario, is answered in the following section.

What does real-world research on nanotechnology say about the risks? Maynard (2006) points out that although it is generally accepted that some nanomaterials and/or technologies may come with the potential to cause harm to both people and environment, the more fundamental problem remains that there is still not much known about these risks:

> Fears over the possible dangers of some nanotechnologies may be exaggerated, but they are not necessarily unfounded. Recent studies examining the toxicity of engineered nanomaterials in cell cultures and animals have shown that size, surface area, surface chemistry, solubility and possibly shape all play a role in determining the potential for engineered nanomaterials to cause harm (Maynard, 2006, p. 267).

This is due to the fact, so Maynard continues, that, at least at the moment, science is still "*ill-equipped to address novel risks associated with emerging technologies. Research into understanding and preventing risk often has a low priority in the competitive worlds of intellectual property, research funding and technology development*" (Maynard, 2006, p. 267). In other words, there are currently two main problems. The first relates to a lack of detection technologies and the second to the fact that the main focus of R&D is on development of new, and predominantly applicable, solutions involving nanotechnology, and not on the things that may potentially hinder nanotechnology progress. Furthermore, Behra and Krug point out that the majority of studies that have been carried out focussed on health and "*the environmental aspects have largely been unexplored*" (Behra & Krug, 2008, p. 253).

4.7 Nanoscale silver

This section will use nanoscale silver as an example to elaborate further on the issue of nanotechnology-related risk. As one of the currently best researched nanoscale elements, nanoscale silver provides an ideal insight into the current available knowledge on nanomaterials, and therefore has also been a chosen to serve as a practical measure for the analysis part of this thesis (Chapter 6). By integrating nanoscale silver into the knowledge framework, assessments can be made with regards to the practical implications of the complexities that are characteristic to knowledge intensive and expertise depended technologies, such as nanotechnology. Here, nanoscale silver provides insight into the risks of nanotechnology that can be assessed by already available data on environmental impacts and by assessing the knowledge, or better put, the expertise requirements needed to address technology related risks.

As briefly mentioned above, one of the very few already known, as opposed to suspected, materials that can cause a risk is nanoscale silver, or simply put, nanosilver. Nanosilver can be defined as a "*nanoparticle or a nanocoating comprised of many atoms of silver engineered for a specified use. Silver nanoparticles are usually engineered to release silver ions, which are the source of antibacterial activity*" (Luoma, 2008, p. 11) and vary in sizes between 1 and 100 nanometres. Silver ions are of 0.1 nanometre in size. In general, positive effects attributed to nanosilver are mostly of medical nature, thus nanosilver products are especially popular in healthcare products, sport and clothing. The FDA reports that nanosilver "*has been recently recognized as a more potent antimicrobial form of silver (Baker et al., 2005; Aymonier et al., 2002; Wright et al., 2002; Melaiye et al., 2005; Sondi et al., 2004; Alt et al., 2004). As an example, Wright et al. (2002) demonstrated that wound dressing coated with sputtered nanoscale silver reduced infections in burns*" (FDA, 2006, p. 8) Current products containing nanosilver, amongst many others, are:

- Washing machines, for instance, produced by Samsung
- Antibacterial make-up instruments
- Curling irons

- Toothpaste
- Acne treatments
- Socks and slippers
- Taekwondo training suits/uniforms
- Bandages and wound dressings
- Beauty soaps, cleansers, make-ups, fabric softeners

As mentioned above, nanosilver has indeed antibacterial and antifungal qualities. As a result, new products containing nanosilver are promoted in a fashion that over the long term might turn out to be counterproductive for the industry. For instance, the Honk Kong based Chinese company Nano Care Technology Ltd. reports on their website about the above-mentioned antibacterial make-up instruments and the benefits of nanosilver in the following way: "*The appliance processed by this means can effectively protect people from the hairdressing-related infections such as trachoma, conjunctivitis, virosis hepatitis, dermatitis and AIDS*" (Nano Care Technology, 2007). In the same vein, JR Nanotech Plc. claim that nanosilver is:

- highly efficacious, fast acting, non-poisonous, non-stimulating, non-allergic, tolerance free and hydrophilic

Both claims are not only highly deceptive, if not outrageous (for instance the advertised protection against AIDS), but also unsubstantiated and thus do not benefit public deliberation on the subject, quite the contrary. Considering the public's current lack of understanding of nanotechnology, or general knowledge thereof, it would be disastrous if that little knowledge that is available were built on false claims and myths. J. Keohane (2010) puts it as follows:

> This effect is only heightened by the information glut, which offers — alongside an unprecedented amount of good information — endless rumors, misinformation, and questionable variations on the truth. In other words, it's never been easier for people to be wrong, and at the same time feel more certain that they're right (Keohane J. , 2010).

Moreover, the statement by JR Nanotech Plc. that their nanosilver is non-poisonous begs the question: Non-poisonous for whom? Although nanosilver is not poisonous to humans, silver is still regarded as a hazard and argyria, that is the condition describing the effects of silver ingestions, is commonly known. The FDA reports that argyria has been documented as early as 980 AD (see FDA 2006).

One of the first researchers looking into potential problems with nanosilver was Troy Benn of Arizona State University. He showed that nanosilver, as used in some already available and commercially marketed socks (here, the marketing aspect focuses on the attributed minimising effects of nanosilver of odour-forming microbial growth) can actually leach out as either silver colloids or ions during washing. This effect, which is the same as the machines containing nanosilver washing produced by Samsung where this effect is actually desired, has the result of nanosilver particles potentially making their way into domestic waste water (Behra & Krug, 2008). Other exposure to nanosilver may occur through contact with burn and wound dressings containing, or surfaces treated with, nanosilver as an antibiotic. The FDA assumes that the increased use of nanosilver products will also lead to an increased human exposure. Potential products the FDA mentioned are, for instance, masks to reduce transmission of infectious agents, home water or food sanitizing kits, kitchen towels, and cutting boards to reduce foodborne infections (FDA, 2006).

The FDA suggests that there should be a research focus on nanoscale silver "*because of increasing use and the gap in knowledge that cannot be filled by information submitted by manufacturers. There are possible toxicity concerns due to the lack of understanding of various aspects of the nanoscale materials*" (FDA, 2006, p. 9) and these concerns will not be addressed adequately unless the following studies are undertaken:

> Nanoscale silver - Conduct (1) absorption, distribution, metabolism and elimination studies in rodents using oral and intravenous routes of administration (including blood-brain transfer), (2) acute (single and repeat dose) toxicity studies (28 days) in rodents, and (3) subchronic, dose-response toxicity studies in rodents (only if warranted). The studies should be conducted on nanoscale silver of one or two sizes (e.g. 10 - 60 nm). The nanoscale material

should be thoroughly characterized before use, and after recovery from tissues (FDA, 2006, p. 9).

What these research requests indicate is that there is large amount of uncertainty when it comes to nanosilver. The FDA stresses that there is a "*paucity of information regarding the environmental disposition (i.e. fate) of nanoscale materials*" (FDA, 2006, p. 4) in general, and due to its popularity amongst manufacturers, a lack of information regarding the environmental fate and impact of nanoscale in particular. In other words, the information received about the amounts of released nanosilver particles, if at all, from manufactures is regarded as either unreliable or incorrect. Toxicology studies have shown that the antibacterial properties of ionic silver occur mainly due to cell death or by compromising cell walls (FDA, 2006). Luoma (2008) states that the complex behaviour of silver is the main reason for existing contradictory conclusions about its risks on both health and environment:

- Different uses release silver in different forms and different quantities.
- Quantifying the mass of silver ultimately released to the environment (or to the body) from a given use is necessary to evaluate the risk associated with that use. Complex geochemical reactions determine how those releases translate to silver concentrations in food, water, sediments, soils or topical applications.
- Silver concentrations in the environment determine impacts. But concentrations in the environment are low compared with those of many other elements, adding to the challenge of obtaining reliable data on environmental trends. Similarly low concentrations of nanosilver might be expected where waste products from its uses are released, although nanoparticle-specific transport and accumulation mechanisms might also be expected.
- The environmental chemistry of silver metal influences bioavailability and toxicity in complex ways (where bioavailability is defined by the physical, geochemical and biological processes that determine metal uptake by living organisms). The influence of environmental chemistry on nanosilver bioavailability is a crucial question.

- Determining potential for toxicity is more complex than usually recognized. The type of test can have a strong influence on conclusions about silver's potential as an environmental hazard. Organisms are most sensitive when tested using long-term chronic toxicity tests and/or exposure via the diet (…). But such data are rare.
- Once inside an organism, silver may be highly toxic, but not necessarily so. The processes that influence internal toxicity (or biological detoxification) might be one of the most important considerations in determining risks from nanosilver.
- Ecological risk is ultimately influenced by toxicity at the cellular and whole-organism level, but that risk will differ from species to species (Luoma, 2008, p. 15).

Luoma argues that although silver is a both a known element and environmental hazard, "[o]*ur knowledge is not adequate to conduct a full risk assessment for nanosilver*" (Luoma, 2008, p. 13). The problem mainly associated with nanosilver is that ionic silver is one of the most toxic metals known to aquatic organisms. Historically, silver releases into the environment have always posed a risk. For instance, when compared to the 1980s, a study of the silver discharges of the San Francisco Bay Area in 2007 were more than 10 times lower (see table below):

Facility		Kg silver release per year	mg silver release per person	Concentration in Bay (ng/L)
Palo Alto*	**1989**	92	415	
	2007	6	27	
Silicon Valley**	**1980**	550	275	26-189 (mean = 113)
	2007	40	20	6

* Data from Homberger *et al.* (2000) and P.Bobel, Palo Alto Environmental Protection Agency (unpublished)
** Data from Smith and Flegal (1993)

Table 10: Discharges of silver into South San Francisco Bay from one Waste Treatment Facility (POTW) and from the combined POTW discharges from the surrounding urban area (Silicon Valley) in the 1980s and 2007 (Luoma, 2008, p. 17)

Although normally concentrations of trace metals are reported as parts per billion (ppb, which equals microgram per litre), silver is reported as parts per trillion (pptr, which equals nanogram per litre). The lowest concentrations of silver (that is dissolved silver in water) can be found in the open oceans (see table below).

Location	**Silver concentration (ng/L)**
Pristine Pacific Ocean	0.1 surface waters 2.2 deep waters
Oceans off Asia (2005)*	Changed from 0.03 to 1.3 in 20 years
South San Francisco Bay (2003)*	6
South San Francisco Bay 1980 1990**	 113 27-36
California Bight (nearest human inputs)***	4.5
Rivers in urbanized Colorado (2000)****	5-22
Effluents of Colorado POTWs (2000)****	64-327
"Protective" Ambient Water Quality Criteria	1,900-3,200
* Ranville and Flegal, 2005; ** Smith and Flegal, 1993 *** Sanudo-Wilhelmy and Flegal, 1992; **** Wen *et al*., 2002.	

Table 11: Typical silver concentration of the water bodies of the world (Luoma, 2008, p. 18)

However, recent research shows that silver concentrations "*changed from 0.03 ng/L in 1983 to 1.3 ng/L in 2002 in surface waters from the open ocean off Asia (Ranville and Flegal, 2005). The distribution of the contamination followed a pattern that suggested wind-blown pollution aerosols were being carried to sea from the Asian mainland by the prevailing westerly winds*" (Luoma, 2008, p. 18). Although the exact sources for that are unknown, it is assumed that they can be linked to recent economic developments; that is, increased economic productivity and output in Asia. The result of this was that offshore silver concentrations rose 50-fold and show the sensitivities of water bodies towards human input (Luoma, 2008). The problems with nanosilver in water is, and this may be one of the reason why nanoscale silver particle may potentially be even more dangerous than the known silver concentrations of the 1980s, that ionic silver is positively charged, thus always seeking to bond quickly with negatively charged ions. Silver uptake or bioavailability, that is the uptake of silver from all sources, is strongly influenced by the form of silver available in the environment and ionic silver is favoured. The uptake is being done by ion transporters, which are proteins. Once taken up, bioaccumulation occurs. Recent studies have found that "*oceanic food webs (phytoplankton) bioaccumulate silver from marine waters to concentrations 10,000 to 70,000 times higher than those found in the water*" (Luoma, 2008, p. 23), thus high ionic silver concentrations can be found at the beginning of the food chain of many aquatic species. With regards to estuaries and marine environments, Luoma concluded that the 'window of tolerance' for silver concentrations is "*relatively narrow because of the strong responses of organisms to relatively small changes in exposure concentration*" (Luoma, 2008, p. 23).

What makes this worse is biomagnification, a process that occurs when a predator accumulates a chemical in concentrations that are higher than in its prey. In this context it means that an organism that takes silver up from its food will accumulate higher concentrations than were present in its food itself. Invertebrates, for instance, have high assimilation and slow loss rates. If, for instance, the above mentioned phytoplankton is the food, then due to biomagnification, the bioaccumulation will also be very high. This can be spun further by looking at invertebrate predators, which also have a high bioaccumulation of silver and so forth (Luoma, 2008). To summarise, and considering what is known at the moment, one can conclude that an increased release of nanosilver into the environment may accumulate to become a serious problem. Although a few studies have been carried out, it is agreed (Behra & Krug 2008, Scheringer 2008, Maynard 2006, Luoma 2008, FDA 2006) that there is still an urgent need for more studies on nanosilver and its toxicology in general, and is ecotoxicology specifically.

4.8 Summary and outlook

One should assume that both governments and corporations have an interest in public deliberation on nanotechnology. This is because the benefits potentially outweigh the risks of such a debate. Maynard argues that "*[t]he spectre of possible harm — whether real or imagined — is threatening to slow the development of nanotechnology unless sound, independent and authoritative information is developed on what the risks are, and how to avoid them*" (Maynard, 2006, p. 267). Considering the long term benefits that are being associated with nanotechnology, be it from a technological progress perspective or by looking at the economic benefits, it seems to be a 'no-brainer' to assume that such deliberations are required. However, although the nanotechnological development and the release of market-ready products is only at its beginning, one can already observe some questionable impacts of product releases.

The examples shown in the previous chapter of the marketing of products containing nanosilver are questionable, especially when considering that there is almost unanimous agreement that there is insufficient knowledge and expertise on the impacts of nanosilver products in particular, and on nanotechnology in general. As previously mentioned, one of the reasons why there is little known about the effects of nanoparticles is because there is a lack of detection mechanisms. Gatti and Montanari point out that "[i]*t has already been proven that inhaled 100nm particles can negotiate the lung barrier within 60 seconds, then show up in the liver and other internal organs within an hour".* (Gatti & Montanari, 2008, p. 33), yet the complexities that are inherent in many nanoparticles are still unknown, and thus reaction with the human body (or the environment) is also not fully clear. Nanopathology, which is the study of effects and diseases caused by nano-sized particles, is still in its infancy and the amount of work that needs to be done is enormous.

In order to maximise benefits and minimise risks at the same time, Maynard (2006) suggests that the science community "*needs to act now if strategic research is to support sustainable nanotechnologies*" (Maynard, 2006, p. 267). He proposes five grand challenges spanning over the next 15 years with the sole aim of bringing focus to complex multidisciplinary issues:

- Develop instruments to assess exposure to engineered nanomaterials in air and water, within the next 3–10 years.
- Develop and validate methods to evaluate the toxicity of engineered nanomaterials, within the next 5–15 years.
- Develop models for predicting the potential impact of engineered nanomaterials on the environment and human health, within the next 10 years.
- Develop robust systems for evaluating the health and environmental impact of engineered nanomaterials over their entire life, within the next 5 years.
- Develop strategic programmes that enable relevant risk-focused research, within the next 12 months. (Maynard, 2006, pp. 268-269)

There are two main things that can be learned from the research on the public's perception of both nanotechnology itself and the risks of nanotechnology. First and foremost, the public has very little knowledge about nanotechnology, and if there is some knowledge, then it seems to be vague. What is more, there also seems to be a distinct lack of interest in nanotechnologies by the public (Krug & Fleischer, 2001). The little available knowledge is of descriptive nature; that is, non-tacit and thus not first-hand acquired knowledge. The second lesson that can be learned is that there is a danger when communicating risks; public opinions will be formed along existing cultural and political orientations, as shown by Kahan *et al.* (2007, 2008). Although polarisation of opinions along the lines of political and cultural predisposition is nothing new (see the political divide over nuclear power for instance), what is new is that the number of available products either containing nanoparticles or being produced by means of nanotechnology will be a thousand times higher. This increase, plus the effects of globalisation and mass communication (including mass mis-communication) have changed the playing field and cannot be compared to previous occurrences with high political polarisation. Kahan *et al.* propose that "*it is imperative that those who have a stake in enlightened public assessment of nanotechnology attend not just to what is said about its risks and benefits but also to who says it*" (Kahan, Slovic, Braman, Gastil, Cohen, & Kysar, 2008, p. 14). Here, the argument is that it is critical to avoid creating the impression in the public that positions on nanotechnology can be associated with cultural dispositions, thus contributing to polarisations along cultural lines of diversity (see also Chapter 2.2). A study by Peter D. Hart Research Associates (2008) suggests that providing little information changed perceptions positively when waging benefits versus risks towards the benefits side, however, it does not automatically confirm the same when assessing risk alone (as opposed to comparing risk to benefits). This is being confirmed by research carried out by the University of Michigan:

> In fact studies undertaken in 2005 and 2006 by researchers at the University of Michigan found that people rarely change their minds when exposed to corrected facts in news stories – and many actually become even more attached to their pre-existing views, especially on controversial issues, a problem that is heightened by the increasing glut of information that confronts

> us, which harbours both new insights and new myths, rumours and downright fabrications (Edwards, 2010).

In other words, people who are adverse towards risk will not radically change their mind, when provided with additional information and *vice versa*. What can proactively been done to promote a better understanding of the risks and benefits of nanotechnology? Maynard (2006) suggests that communication activities should be developed that allow for the summarisation of technical information, their critique and synthesising for interested parties, including decision- makers and consumers. Currall *et al.* point out that "[*a]cademic bodies, such as the Royal Society and Royal Academy of Engineering in the United Kingdom and the National Academies in the United States, should be asked to summarize and update the current state of knowledge about risks and benefits of nanotechnology. Based on these findings, interagency 'societal impact' subgroups can be formed to coordinate education and public outreach efforts by creating a clearing house in each country that synthesizes information about the health and environmental impacts of nanotechnology, including performance indicators and the latest scientific findings on risks and benefits"* (Currall, King, Lane, Madera, & Turner, 2006, p. 155). Both ideas rely, however, on input, willingness and suggestions that need to come from governments, or at least government bodies. Yet, this is also where some of the problems with knowledge-intensive technologies lie:

> America leads the world in science and technology, yet its political leadership often seems detached from its scientific expertise. Indeed, the Bush administration has acquired a reputation for treating science with disdain. … The Bush administration has repeatedly drawn criticism not just for neglecting science, but for manipulating and suppressing science for political ends (New Scientist Magazine, 2008, pp. 8-10).

Moreover, Bowman and Hodge suggest that "*[g]overnments, regulatory agencies, and industry are only now beginning to understand the depth of the scientific information deficits that exist in relation to the potential human and EH&S {environmental health and safety, sic!] implications*" (Bowman & Hodge, 2008, p. 484). The argument is, according to the authors, that, in addition to the currently existing information deficits, there is a lack of certainty and *"the difficulties and lengthy development of new legislative regimes, the complexity of the nanotechnology itself and the possibility of large economic rewards all appear to be significant factors associated with why governments have not reacted hastily to calls"* (Bowman & Hodge, 2008, p. 484) for nanotechnology specific regulation.

A second perspective, which has briefly been mentioned in this chapter, needs to look at what could happen if nanotechnologies were used by rogue nations or terrorist groups? Gatti and Montanari quickly highlight that "*[t]oday's science has no experience with the novel, nano-scale environmental pollution caused by the innovative technologies of twenty-first century wars*" (Gatti & Montanari, 2008, p. 33). Although one needs to stress that these types of technology/weaponry are not yet available, considering the progress that nanotechnology has made over the past 10 years, one can assume that it only remains a question of time. According to Gatti and Montanari (2008), not much research has been done in this regard. Considering how little is known about nanotechnology risks, this is not surprising. As with nanotechnology in general, weaponisation of nanoscale materials is still largely unknown, but the potential nanotechnology offers suggest that will change soon. Combining this assumption with what is known already about the public perception of nanotechnology, one can further assume that there is an enormous potential for public dispute on this subject matter. The complexities, however, that are inherent in these knowledge-intensive and expertise-dependent technologies are very likely to complicate public deliberation on these subject matters.

Where to go from here? Nanotechnology is, simply put, extremely complex and when it comes to informing the public nanotechnology is expertise dependent. The following chapter will provide further insights into the perceptions of risks by both experts and non-experts and also provide an overview of recommendations and recommended actions to address these issues. These recommendations and recommended actions are then used in Chapter 6, where they will be analysed against the knowledge framework.

5. Nanologue

5.1 Introduction

In order to investigate available data, information, knowledge and expertise of nanotechnology and the risk of nanotechnology, the following research carried out by Nanologue will be used to highlight areas of concern and typical responses from laypersons and experts. Nanologue's study has been chosen over other research conducted (Currall, King, Lane, Madera, & Turner, 2006; Kahan, Braman, Slovic, Gastil, & Cohen, 2008; Peter D. Hart Research Associates, 2008) as it goes beyond standard opinion polling. The study was a comprehensive mix of a number of public and expert engagement exercises and it has been the most complex and extensive study undertaken to date with regards to collated qualitative data on the preceptions and risks of nanotechnology. According to Türk, "*Nanologue brings together researchers, businesses and representatives from civil society from across Europe to support dialogue on the impact of NT on society, and is part of the commission's response to the challenges highlighted in the recent Nanotechnologies and Nanoscience (N&N) Action Plan for Europe*" (Türk, 2005, p. 56). In addition, Nanologue's study takes detailed differentiations of risks associated with nanotechnology into account and makes a distinction between laypersons and experts and their respective take on nanotechnology related issues, thus delivering a more detailed overview of the current understandings of the subject matter.

For the sake of clarity, it should be mentioned here that the use of Nanologue's studies, and therefore, data, for the purpose of this thesis also means using, or relying, on descriptive knowledge and/or explicit information. Nanologue's studies have been approached, and therefore, utilised as a main source of data. As discussed earlier, the act of adding meaning to data results in the production of information, and hence, knowledge. Using Nanologue's data, analysing and then recomposing it for the purposes of this chapter also means adding to the overall body of knowledge and going beyond the findings of Nanologue. Nanologue (2006) published outcomes of interviews and a workshop where both researchers and members of civil society were asked about the risks and benefits. For instance, the tables below provide an overview of the perceived benefits and risks of nanotechnology, as stated by the participants of Nanologue's study. These finding corroborate that of other researchers (Kahan *et al.*, 2007, 2008; Currall *et al*. 2007; Peter D Hart, 2008) who also have investigated the current perceptions of benefits and risks of nanotechnology with regards to the scope of what is either known or being assumed by the participants of these studies.

Benefit	Votes
Better medical diagnosis	11
Reduction in environmental pollution / impacts	10
Better drug delivery	5
Food safety (improved packaging)	3
Reduced Cost / Material use = Improved efficiency	3
Greater Access to Resources (reduction in conflict)	3
Reduced cost of Healthcare	3
New technologies / New economies	1
Next generation information technology	0

Table 12: Benefits prioritised (Nanologue, 2006, p. 115)

Risk	Votes
Toxicity of Nanoparticles	12
The Nanobubble[30]	9
Nanodivide	7
Use of NT for military applications / terrorism	5
Products we don't want	4
Economic Dislocation	2
Privacy	1

Table 13: Risks prioritised (Nanologue, 2006, pp. 115-116)

The following chapter will provide further insight, especially when it comes to the composition of such risks or benefits analyses with regards to the differing type of participants, such as nanotechnology experts or members of the civil society. Moreover, Nanologue's finding will be critically evaluated and assessed against the knowledge framework and against findings of other research in order to address the core objectives of this thesis.

[30] "*The Nanobubble – a concern held by the majority of the delegates that there was not enough focus and too much hype surrounding investment in nanotechnologies and this would result in a "bubble" that would eventually burst*" (Nanologue, 2006, p. 116).

5.2 Nanologue's study of nanotechnology

Nanologue, funded by the EU's 6th Framework Programme[31] undertook intensive studies of researchers and members of the civil society on their opinions of environmental, legal and social aspects (ELSA) of nanotechnology. Following their initial review of ELSA, their studies and workshops aimed at obtaining a deeper understanding of ELSA and the risks of nanotechnology. Using interviews and workshops, their intention was to:

- engage with representatives from R&D, marketing and users of nanotechnology in a dialogue on the benefits and potential ELSA on nanotechnologies in order to capture their perspective on the issue;
- speak to societal groups in order to further develop and substantiate the benefits and potential impacts of nanotechnologies;
- facilitate the process of prioritising the benefits and potential impacts identified;
- contribute to the development of the subsequent project work, including the development of scenarios exploring how business, civil society and public institutions can engage effectively in a dialogue on the ELSA of nanotechnologies (Nanologue, 2006).

Nanologue uses the term "researcher" as a synonym for scientists and technologists that are either based in universities or the business and are involved in research and development of nanotechnology based applications in the areas of medical diagnosis, food packaging and energy conversion and production. For members of the civil society, Nanologue widened the definition beyond that of voluntary civic and social organisations or institutions and included others "*who are involved or interested in understanding, marketing, regulating, monitoring, writing about nanotechnologies or helping to develop market-relevant products using nanotechnology applications*" (Nanologue, 2006, p. 8). Nanologue stresses that the involvement of members of the civil society was not meant as a representation of the public's perception of nanotechnology, but to ensure a balanced view between researchers and civil society.

[31] FP6-2003-NMP-TI-3-main.

Considering that Nanologue used this broader definition of civil society, the awareness of nanotechnology and related risks was slightly above that of other studies on the public perceptions, for instance by Currall *et al.* (2006). Nanologue explains that this is due to how the members of civil society have been selected: "*As a result this group was expected to have a better understanding of the issues surround NT than a more traditional group of representatives from civil society*" (Nanologue, 2006, p. 7). To a certain extent, this is somewhat unfortunate, as it would have been useful to fully compare the result between Nanologue's civil society and the results of other research that interviewed the public in order to identify differences between the interviewed groups. In addition, it would have also been useful to have an overview of exactly how Nanologue's members of civil society differ from that of the 'ordinary' public. Since Nanologue did not provide any details about the members of civil society beyond the explanations shown above, it is difficult to assess the size of the assumed knowledge gap, or differences in pre-existing knowledge, between Nanologue's civil society and the 'ordinary' public.

5.2.1 Risk perceptions

A number of researchers that have been contacted and asked to participate did not respond. Nanologue suggests that some of the contacted researchers were "*either overloaded with interview requests and therefore not able to participate or were simply not interested*" (Nanologue, 2006, p. 8). As a result, the Nanologue team concluded that "*the group of experts who agreed to participate in the interviews takes an above average interest in NT-related ELSA aspects*" (Nanologue, 2006, p. 9). This needs to be taken into consideration when looking at the results.

The participating researchers were interviewed either by telephone or in person, and also asked to complete a questionnaire. The participating members of civil society were invited to a one-day workshop[32] where the delegates were asked to:

- list the main risks and benefits of nanotechnologies;
- vote for the most important risks and benefits and prioritise them;

[32] Held in Edinburgh on 05.09. 2005.

- vote on how certain they were that these risks and benefits would be relevant by 2015;
- discuss the barriers to better communication between stakeholders concentrating on the role of scientists;
- make recommendations to overcome these barriers (Nanologue, 2006, pp. 9-10).

In their 2004 study, Nanologue concluded that there is neither a common ground amongst scientists nor an understanding on what exactly the ELSAs of nanotechnology are: "*The question remains, however, what exactly are the ELSA of nanotechnology, and what to do about them. Indeed, we should expect this question to remain open for a long time*" (Strand 2004, quoted in Nanologue 2006, p. 10). As a result, Nanologue decided to focus on a variety of opportunities, threats and risks of nanotechnology and instead of looking at this area generically, Nanologue chose seven particular aspects for the research:

- Environmental performance
- Human health
- Privacy
- Access
- Acceptance
- Liability
- Regulation & Control[33]

Four of those areas need to be further looked into: environmental performance, human health, access and acceptance. These areas are of particular interest to this thesis, the first two, as they reflect the current understanding of risks, and the latter two because they deal with information and the group of non-experts. The table below provides an overview as to why these selected areas are of interest: their relevance.

[33] Nanologue investigated all of these areas generally as well as industry specific, namely the areas of: medical diagnosis, food packaging and energy conversion and production. For the purpose of this research, only the general findings will be used, but not the industry specific findings.

Area	Relevance
Environmental performance	The assumption is that nanotechnology has a direct or indirect impact on the natural environment. Potential issues are: eco-efficiency, eco-toxicity, bioaccumulation.
Human health	The assumption is that nanotechnology has a direct or indirect impact on the human wellbeing. Potential issues are: Toxicity, particle accumulation, disease diagnosis and treatment, or drug delivery.
Access	Potential issues are: How do individuals or groups get access to nanotechnology, including physical access, access within and between societies/countries? How to deal with issues such as affordability, intellectual property rights, concentration of power?
Acceptance	The assumption is that level of public acceptance of nanotechnology has a direct or indirect impact on the development, production and marketing of nanotechnology products. Potential issues are: delayed introduction of nanotechnology products and/or political divide on nanotechnology issues.

Table 14: Selected areas and their relevance (Nanologue, 2006; also Kahan *et al.* 2007, 2008)

Nanologue states that all researchers interviewed were aware of the ELSA of nanotechnology and that it can be assumed that the interviewees had an above average awareness and knowledge. However, and to reiterate, more than half of the originally asked researchers were not willing to participate. Nanologue assumes that, although the interview request "*explicitly stated that no expertise on ELSA is required, some might have not responded simply because they felt not comfortable with or well informed about the topic*" (Nanologue, 2006, p. 13).

When asked how they informed themselves on the ELSA of nanotechnologies, the researchers responded as follows:

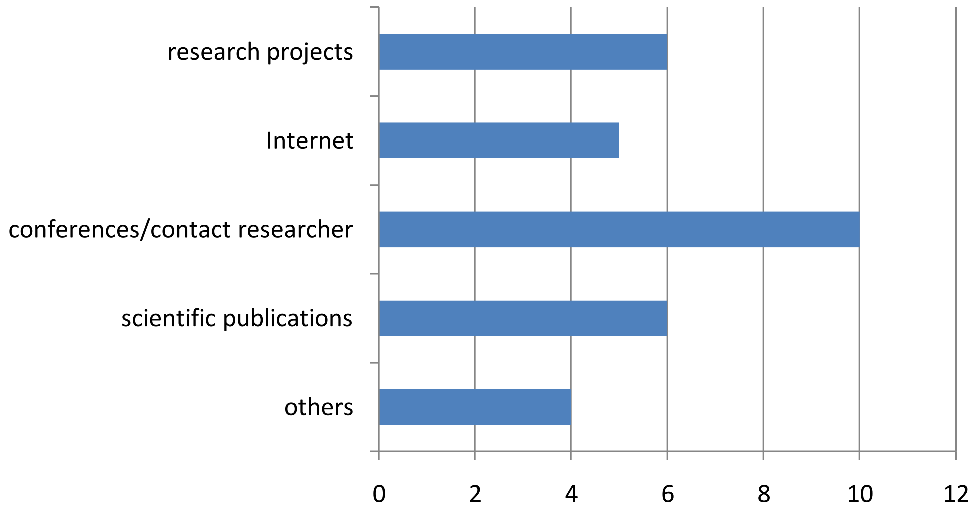

Figure 11: Information channels mentioned by representatives from research by numbers (Nanologue, 2006, p. 13)

In comparison, when asked how the members of the civil society informed themselves on the ELSA of nanotechnologies, they responded as follows:

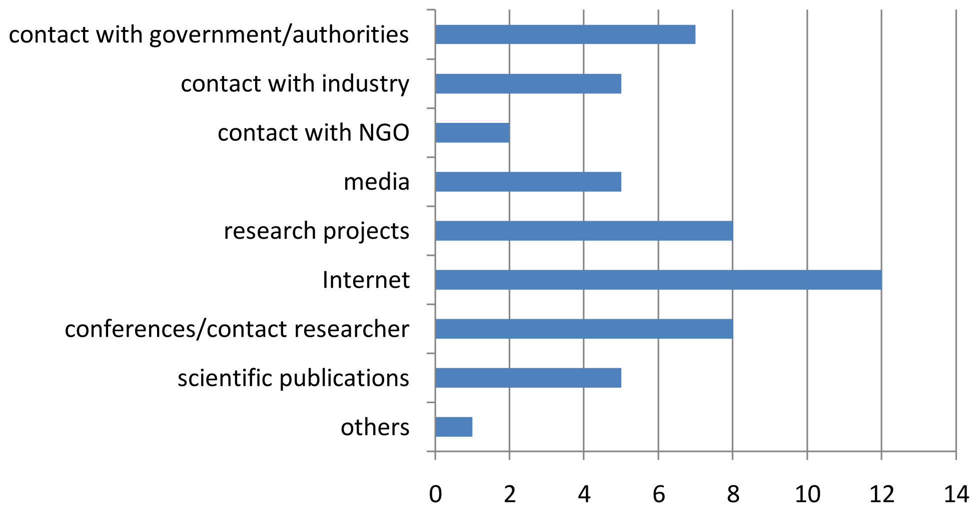

Figure 12: Information channels mentioned by representatives from civil society by numbers (Nanologue, 2006, p. 13)

When members of the civil society were asked if they felt adequately informed on ELSA of nanotechnologies, "[r]*oughly a third said yes, but mostly with a caveat. Many of the interviewees commented that they follow the nanotechnology debate closely as part of their work or interests, but felt that the information had not yet reached the wider public domain*" (Nanologue, 2006, p. 13). In other words, although circa a third said that they felt informed, "*they were not necessarily representative of the general public, who might not be adequately informed. … It was also posited that whilst there* *was an adequate amount of information 'out there' this did not mean that the ELSA were well understood [i.e. information itself is not enough]*" (Nanologue, 2006, p. 13). In addition, another third was not sure whether they felt adequately informed, arguing that there is lot of information 'out there', but had difficulty deciding where to even start. This confirms the assumption that the members of the civil society represented in Nanologue's study were better informed than the general public. The results of studies by Kahan *et al.* (2007, 2008) and Currall *et al.* (2006) confirm this. There was a general feeling that the current debate on ELSA of nanotechnology "*had no structure and had not advanced*" (Nanologue, 2006, p. 13). The remaining third responded with not feeling adequately informed.

Nanologue interviewed five researchers from various nanotechnology backgrounds in order to assess their perspective on nanotechnologies in general. Most of them were personally interested in ELSA, felt well-informed, and some of them had already been involved in discussing ELSA topics with colleagues. "*However, leaving their area of expertise and being asked about ELSA of NT in general most participants expressed they lacked an overview and would only be able to provide a few examples*" (Nanologue, 2006, p. 30). As a result, the researchers demanded additional information on nanotechnology for non-experts, for instance, if these non-experts were involved in creating regulation.

Human health aspects and environmental performance were the areas that the researchers pointed out to be of highest relevance. With regards to public acceptance, the researchers were asked to provide a vision of nanotechnology development until the year 2015, issues such as fraud, ethical concerns, and clarification of health risks were mentioned on several occasions. However, concerns about accessibility were considered "*to deserve only more or less attention*" (Nanologue, 2006, p. 31).

Nanologue points out, that the researchers did not differ substantially in their opinions and that the most common statements referred to:

- Environmental risks (eco-toxicity) and environmental opportunities (resource efficiency gains);

- Human health risks (toxicity) and opportunities (disease treatment and diagnostics);
- Parallels to the GM-debate (Nanologue, 2006, p. 35).

The table below summarises the main findings of the selected areas and the researchers' overall perceptions.

Area	Researcher's perceptions
Environmental performance	Nanotechnologies would eventually contribute: • to improvements in the overall environmental performance due to eco-efficiency gains, • miniaturisation effects or enhanced mechanical properties as well as through NT-based environment technology applications, e.g. testing and monitoring systems. The overall impact of nanotechnologies was seen positive, but the potential eco-toxicity was perceived as a risk.
Human health	This was perceived as one of the most important ELSAs and benefits were expected to appear in the areas of: • medical diagnosis and treatment • improved food safety and water treatment Potential drawbacks were risks of misinterpretation of diagnostic data and the possible wrong treatment of diseases (this, however, is not nanotechnology specific) . Other risks were mentioned in connection with free nanoparticles. Lab-on-the-chip (LOC) developments were considered as being one of the most relevant ELSA.
Access	Access was only considered to be an issue of medium relevance. Sophisticated nanotechnology developments were expected to be limited to the most advanced industrial nations. The access and abuse of nanotechnologies by either criminals or political regimes was not mentioned by any of the interviewees.
Acceptance	All researchers felt that public acceptance of nanotechnology to be crucial for the development of nanotechnologies and that it is a risk in itself. Some even regarded it as being more important than potential risks themselves. It is expected that public acceptance will depend on the availability of applications and their practical use, i.e. using nanotechnologies in consumer goods or as part of medical treatment will have better perception than in other areas.

Table 15: General perception of researchers for four selected areas

However, one area was left out of the ELSAs altogether: the use of nanotechnologies in military applications. The reasoning behind this was that this area employs different measures of what is social and ethical. Moreover, it was acknowledged that this area has other incentives and priorities.

The opinions of the members of civil society differed to that of the researchers, althoughnot in areas one would expect. When the members of civil society were asked which of the ELSAs or risks debated by the media were most relevant, the participants listed risks three times more than potential benefits.[34] One explanation for this was that discussions about the benefits of nanotechnology happen mostly in business-to-business (B2B) relationships, yet this often does not reach the public. The media, on the other hand, was seen as mostly reporting about the risks.

Area	Perceptions of members of civil society
Environmental performance	Potential benefits were seen in: • improvements in nano-filtration of water, • improved energy storage and transfer. Eco-toxicity was seen as the most pressing risk, however less agreement was found with the following statement "nano-materials present an eco-toxicological risk, in particular in the disposal phase."
Human health	The participants agreed that nanotechnology applications will • enhance human health through earlier disease detection and • better-targeted application of treatment. A third of the participants were concern over toxicity, nanotechnology as an occupational hazard and the use in food.
Access	The most prominent risks mentioned here were: • nanodivide[35], • the use of patents, • corporate power and economic disruption.
Acceptance	It was noted that there is a potential risks associated with media coverage of nanotechnology related threats, 'grey goo' and the vision of nanotechnology destroying the world (admittedly, the interviewees pointed out that these assumptions were not based on sound science). Also, the "*majority of interviewees were also more or less sure that there would be a public backlash against the use of nanomaterials in areas such as food and medicine*" (Nanologue, 2006, p. 41).

Table 16: General perception of members of civil society for four selected areas

A comparison between the two tables shows that the researchers and the members of civil society more or less agreed on the first two areas; environmental performance and human health. However, considering that there was less agreement amongst the

[34] Nanologue, however, admits that this may have been triggered by the way the unprompted question was framed (Nanologue (2006).

[35] In this context, Nanologue uses the term nanodivide as a collective term to cover a number of concerns. Nanodivide has scored as highly likely to be an issue by 2015 and includes:

- Concentration of power and access to nanotechnologies (i.e. cost of medical treatments);
- Access and equal distribution of the technology globally;
- Access within society or between societies (Nanologue, 2006, p. 48).

members of civil society on the potential of nanomaterials posing an eco-toxicological risk, and that only a third were concerned about the human health risk, the researchers seemed to be a little more concerned in these two areas. Although Nanologue did not provide any reasons for this, as the thesis will show later, both prior and acquired knowledge by the researchers are likely to be contributing factors. The third area, access, showed the most prominent division between these two groups. Whereby the researchers considered this to be of (only) medium relevance, their concerns seemed to focus more on abuse or misuse by criminals or regimes. Members of civil society had a different take on the subject, and were mostly concerned with the nanodivide (that is, a potential gaps between people who have and who do not have access to nanotechnology), and restrictions that come with the use of patents and corporate power. Although there was agreement in terms of the expected result, public acceptance was viewed differently with regards to the 'why' and 'how'. The researchers assumed that, with increasing availability of potential useful products, the public will come to accept nanotechnology and see it as a benefit. The participants of the civil society, however, argued that the media coverage is negative *per se* (see Chapter 6.3.2.2) and hence assumed that there would be a public backlash.

5.2.2 Areas of concern as highlighted by the members of civil society

As the members of the civil society were not just mere members of the 'ordinary' public, but rather a mix of professionals who work in areas related to nanotechnology, a number of their viewpoints require further attention. It is important to make a distinction here, as the members of civil society are not only giving their own opinions on areas of concern, but also provide an opinion about how they perceive the public think about them. The following provides an overview of what these areas of concern are. It will not only show which areas are considered to be important in the future, but also the areas which are perceived to require the most urgent action, whether attention to some of the issues will increase or decrease and which issues the public views as important.

When asked how much attention any of the ELSAs deserve, the members of civil society answered as follows (see figure below):

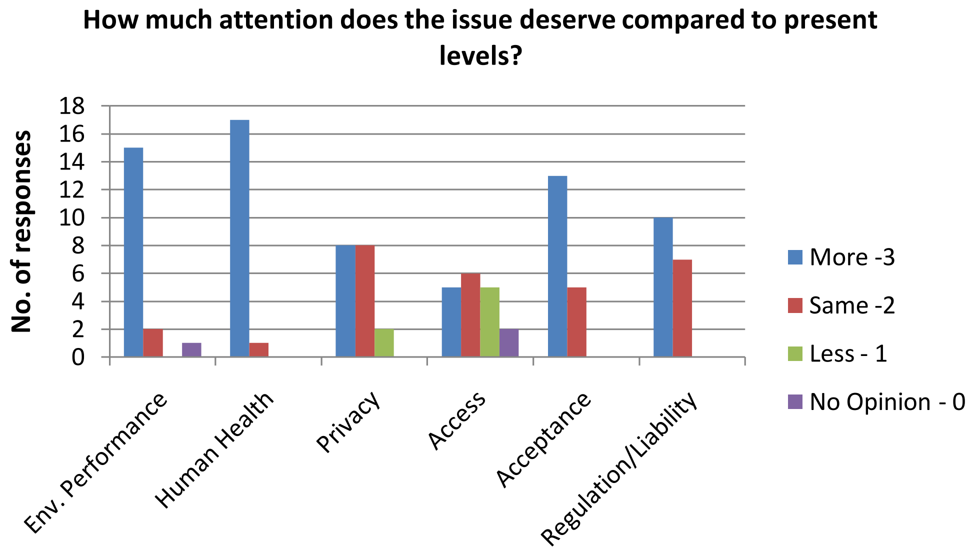

Figure 13: ELSA priorities of interviewees (Nanologue, 2006, p. 42)

Human health scored the highest, followed by environmental performance and public acceptance. The area of access scored the lowest. This is interesting, because when asked which of the ELSAs require the most urgent actions, the members of civil society did not mention public acceptance at all.

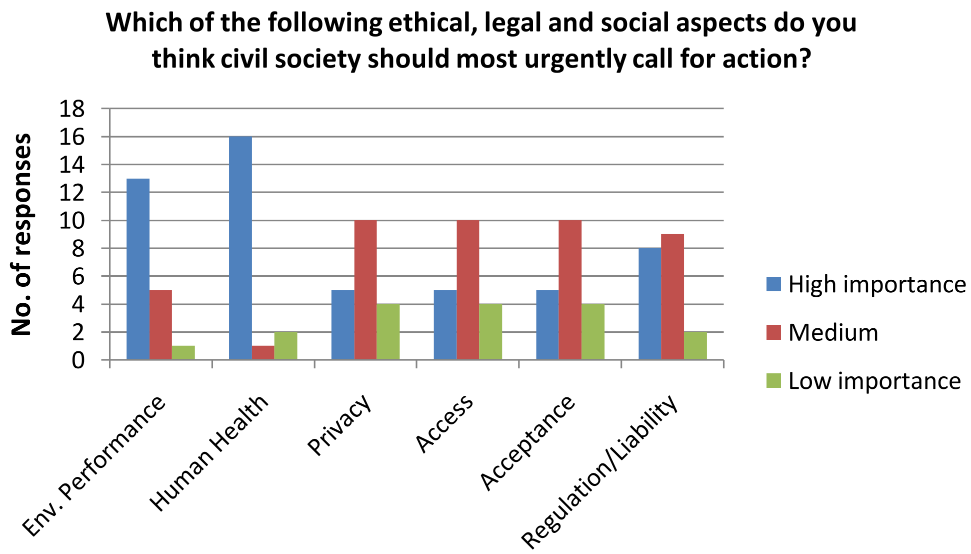

Figure 14: ELSA of civil society (Nanologue, 2006, p. 42)

Access was also seen as a concern of only medium importance (see figure above). In fact, Nanologue itself argued that there were disagreements as to whether society should be concerned with area of access (and liability and regulation). Human health and environmental performance are considered to be the two areas that not only require the most urgent action but are also expected to gain the highest levels of attention in the future. Public acceptance is also perceived to be an area that deserves more attention, but is has not been listed as an area that requires urgent action. However, this is also due to how Nanologue has collected the data; the participants could only choose between the six options provided (environmental performance, human health, privacy, access, liability, regulation). No information was given as to why acceptance was not on this particular questionnaire. This is unfortunate, as its inclusion would have allowed better insight into whether public acceptance is an area requiring urgent action and it would have allowed for better comparisons with the answers provided to the other questions.

When the members of civil society were asked which area is most likely to receive more, less or the same amount of attention in the future, the areas of public acceptance, however, scored higher than environmental performance, which was *on par* with access (see figure below). In fact, public acceptance was seen as the second most important concern after human health; scoring slightly higher than environmental performance.

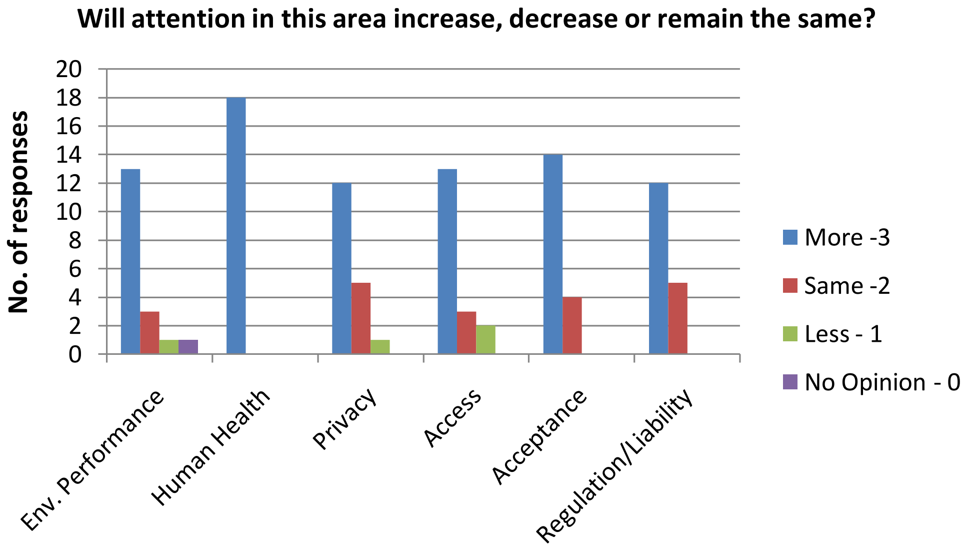

Figure 15: Will attention increase, decrease or remain the same? (Nanologue, 2006, p. 43)

Unfortunately, Nanologue does not provide any further insight as to whether the members of civil society see public acceptance as an important issue because of their prior knowledge of nanotechnology or whether the members of civil society see public acceptance as an issue because they assume that, in the future, the public will see this as an issue.

Finally, when the members of civil society were asked how they rated the general public's level of attention, the results were as follows (see figure below):

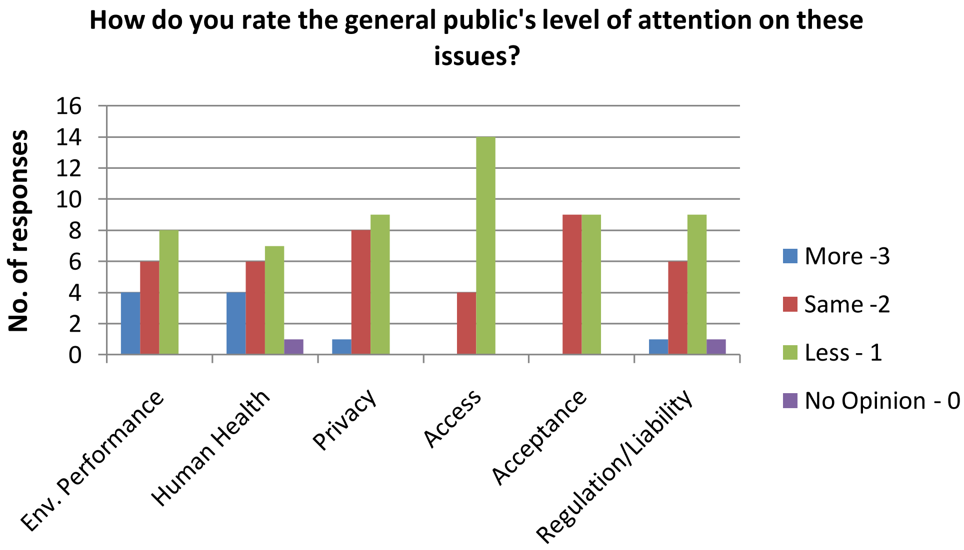

Figure 16: The general public's level of attention, as rated by the members of civil society (Nanologue, 2006, p. 43)

This figure requires some explanation. One can see that the area in which the participants scored most with less (meaning it is likely that there will be less attention in the general public) is the area of access. This is due to the fact that the participants were "*not happy to answer this question as they felt that public level of knowledge was generally poor. However, there does seem to be some differentiation with most interviewees marking the level of knowledge on Access lower*" (Nanologue, 2006, p. 43). Similarly, public acceptance did not score particularly well. This begs the question regarding what impact the members of the civil society's prior knowledge had on these results. According to these results, the members of the civil society see environmental performance and human health as the two main areas where to which the public will pay attention, followed by privacy concerns.

To summarise: environmental performance, human health, and public access are the three main areas that stand out. Despite the unfortunate omission of public acceptance from one of the questionnaires, these three areas are seen at the forefront of required actions as well as current and future attention. However, due to the composition of this group, these members of the civil society should not be confused with the general public. There is no doubt that they cannot be classified or described as experts. Nonetheless, their prior knowledge of the subject matter may have played a larger role than Nanologue either expected or declared.

5.2.3 Recommendations and recommended actions

Nanologue points out that although all participants had a general awareness of certain ELSA of nanotechnologies, discussions concentrated more on risks than benefits. Amongst both groups, researchers and members of the civil society, there was consensus on concerns with regards to potential impacts of nanoparticles on the environment and human health, and that there is little known about the life cycle of nanoparticles yet and more is to be learnt about the 'end of life impacts'. On a positive note, there was a general expectation that nanotechnologies can potentially positively impact efficiency in material and energy use leading to a potentially positive economic benefit. However, with regard to public awareness, Nanologue concluded that it recognised that the information on ELSA is neither comprehensive nor centralised and that public awareness is low. Moreover, although there was agreement of the importance of discussing ELSAs, there were doubts about what is needed in the public domain, or in other words, what is needed to better inform/involve the public. This, at least to a certain extent, explains why there was an assumption that "*a public backlash is almost inevitable*" (Nanologue, 2006, p. 58). This goes hand-in-hand with the fact that transparency and the need for the business to share as much information as possible were strongly seen as being important. Finally, and perhaps surprisingly, there was little agreement either within or between the researchers and members of civil society about the need for new regulation.

Following the interviews, workshop and interpretation of results, there are a number of recommendations Nanologue makes. First, there seems to be a need to stress that the risks of nanotechnology are often 'lumped together' (instead of discussing them domain specific) when discussing nanotechnology-related risk in public. This seems to be the main cause for the assumption that a public backlash is very likely. Thus, Nanologue stresses, "[*t]he debate of risk often does not differentiate between applications*" (Nanologue, 2006, p. 73). However, this does not seem to be limited to public discussions: "*not only the general public, but also other non-expert decision-makers in politics, business and society might also mix things up*" (Nanologue, 2006, p. 74). Therefore, the recommendation is that dialogue and communication need to be context or application specific. The next area touched upon is transparency:

> Whilst there is a danger that too much information could lead to confusion or disengagement from the issue, there is a far greater danger that a lack of transparency will result in a lack of empowerment and a backlash from the public. The discussion on GM raised serious questions mainly but not exclusively about corporate transparency in particular, and this must be overcome (Nanologue, 2006, p. 73).

Especially the reference to GMO echoes concerns of other research undertaken, for instance, by Kahan *et al*. (2007). As the results have shown, there seems to be a large amount of information 'out there', but not all is accessible, nor is it available in a central place. "*Making this information available at the internet is an obvious choice, since the interviews showed that both target groups use it as a prime information source*" (Nanologue, 2006, p. 76). One of the direct results of this is the lack of knowledge of both nanotechnology itself and the ELSAs of nanotechnology. Nanologue concludes that *"[l]ack of knowledge about nanotechnologies as well as ELSA of NT-applications can not only be attributed to the complexity or novelty of the subject"* (Nanologue, 2006, p. 76).

There are a number of additional raw data items in Nanologue's study that are of special interest to this thesis. In their appendix, Nanologue provides a full list of recommendations that go beyond what has been discussed above. Selected recommendations that are particularly of interest are listed below:

- The education system needs to be updated to integrate the discussions around science and society, cost / benefit. Critical thinking introduced into all levels of education. (Obviously this is not unique to NT)
- Trans-disciplinary education of Natural / social scientists
- In corporate science there needs to be close co-ordination between those responsible for ELSA at board level and the technicians.
- Information about new tech e.g. NT should be available at schools even at early levels (Nanologue, 2006, p. 117).

Furthermore, what became clear is that a distinction between nanotechnology experts and experts of ELSA (of nanotechnology) needs to be made. Most researchers in Nanologue's study were not comfortable with ELSAs of nanotechnology and indicated that they lacked an overview of the subject matter that is ELSA. Nanologue also expressed that there was some concern about the experts who declined to attend, although it was stated that prior knowledge of ELSA is not required. Also, a clear distinction can be made as to how the experts and the participants of civil society informed themselves about the subject matter. The researchers mostly used conferences, contact with other researchers, scientific publications and research projects; the members of civil society mainly used the Internet, then research projects, conferences and contact with governments/authorities. Although this already indicates a differentiation between how these two distinct groups inform themselves, again, the results from the members of civil society do not seem to represent the public as a whole. Their prior exposure to the subject matter clearly played an influential role here. Other communication channels were also mentioned, although in lower numbers that could be expected from representatives of the public, namely the media, NGOs and contact with the industry.

5.3 Summary

The main aim of this chapter was to review, filter out and select data that can be used for analysis purposes. It has identified the currently perceived risks by both experts and non-experts. Furthermore, as Nanologue's research is the most comprehensive carried out to date, it also provides detailed recommendations and recommended actions to address the identified risk. The available data was comprehensive and provided more than sufficient insights for the purposes of this research. The data will be analysed and compared to the knowledge framework in the next chapter.

However, Nanologue's study also revealed a paradox. Nanologue argue that they 'widened' the interpretation of what members of the civil society are for the purposes of their research, by including those "*who are involved or interested in understanding, marketing, regulating, monitoring, writing about nanotechnologies...*" (Nanologue, 2006, p. 8). Here, questions needs to be asked whether this achieved the desired outcome. This is, because, one could argue that by including those who are involved or interested in marketing, monitoring or writing about nanotechnologies actually do not represent the 'average' member of the public. When comparing a number of responses from studies carried out by other researchers, such as Kahan *et al.* (2007, 2008) and Currall *et al.* (2006) to the findings of Nanologue in areas such as public awareness of nanotechnology and related risks, then it does not come as a surprise that Nanologue's findings of what 'their' members of civil society knew about nanotechnology was above average. Although Nanologue clearly stated they expected to see better results than they might have received from a "*more traditional group of representatives from civil society*" (Nanologue, 2006, p. 7), the questions remains whether the study would have not yielded more accurate results, if they had decided on average members of civil society that did not have an expressed interest or involvement in nanotechnology. Nevertheless, Nanologue's approach to civil society has one, perhaps unexpected, benefit; the members of civil society they had chosen represent a new group that had not been investigated before: people with some prior knowledge, or better said, with descriptive knowledge of nanotechnology. They are not experts; that is, they do not belong to the groups of people that have knowledge by acquaintance, but also do not belong to the group that have no knowledge (the majority of people interviewed in other surveys, such as those of Kahan *et al.* (2007, 2008) and Currall *et al.* (2006)).

6. Analysis

6.1 Introduction

Taking the aforementioned complexities that are inherent in new and emerging, and at the same time often converging, technologies and stripping them down to the required and available sets of knowledge allows a closer view into the idiosyncrasies that come with those forms of domain-specific knowledge intensity. Such a view is required in order to understand better the problems and risks that are, or can be, associated with new technologies of increasingly complex nature. Therefore, a knowledge framework has been established and will be applied to both the nanotechnology case (Chapter 4) and the qualitative data provided by Nanologue (Chapter5). This framework covers the various types of knowledge that have been discussed in Chapter 3, that is, knowledge by acquaintance and tacit knowledge vs. knowledge by description and explicit knowledge as well as policy knowledge. Their subsequent application to the nanotech case and to the findings of Chapters 4 and 5 aims to identify issues not only with regards to the policy recommendations made, but also with regards to involving the public in an open discourse about nanotechnology. The goal is to validate the importance and applicability of these types of knowledge in an analytical framework that is able to deal with complex, but more importantly, with knowledge-intensive subject matters.

Following the introduction of their findings, the knowledge framework is used to assess a number of Nanologue's suggestions in regard to policy-making and recommendations that focus on dealing with the public. In addition to assessing Nanologue's recommendations, recommendations of other studies are assessed as well in order to get a better overall picture of the quality of recommendations currently being made with regards to nanotechnology research and its wider implications. As part of this critique of current policy recommendations and recommendations on how to better involve the public, two alternative options will be introduced and discussed.

6.2 Applying the knowledge framework to different knowledge types

First, knowledge by acquaintance is discussed and applied against the nanotechnology context followed by tacit knowledge, knowledge by description, explicit knowledge and then policy knowledge and information. The reason for this particular order is that both knowledge by acquaintance and tacit knowledge are not only very similar, but they can also be classified as direct knowledge. The very generic term of expert knowledge is an example of direct knowledge. Knowledge by description and explicit knowledge can be classified as indirect knowledge, and thus the knowledge that is mostly available to non-experts or laypersons. The aim of this analysis is to identify the nature of these knowledge types when viewed from a nanotechnology perspective, what attributes they have and also what limitations with regards to their user base, and when it comes to communicating them, to their potential target bases.

6.2.1 Knowledge by acquaintance

In the context of nanotechnology, and, particularly, in the context of the example of nanoscale silver particles as shown in Chapter 4.7, knowledge by acquaintance refers to knowledge that has been directly acquired through first-hand and thus direct exposure to the subject matter (see also Table 5). A researcher working on specific nanotechnology problems can be identified as having knowledge by acquaintance. For instance, Oberdörster *et al.* investigated the impacts of the exposure of water fleas (*Daphnia magna*) to nano-iron particles (Oberdörster, Stone, & Donaldson, 2007). This direct experience not only led to knowledge by acquaintance but was also based on existing tacit knowledge. As a result, while supposing that the general conditions as laid out in Chapter 3.4 have been met, Oberdörster *et al.* gained acquired expertise in the area of toxicology of nano-sized particles. Similarly, Babu *et al.* have investigated the effects of nanosilver on cell division and its potential damage to genetic material (Babu, Deepa, Shankar, & Rai, 2008). As a result of this study, Babu *et al.* now possess acquired knowledge (and in this case, the evidence) of the potential genotoxicology[36] of nanoscale silver particles on plants. Guo *et al.* investigated the growths of Boron rich nanowires and by doing so acquired first-hand knowledge on the synthesis of

[36] The term genotoxic means 'damaging the DNA', thus potentially leading to mutations and cancer. Genotoxicity describes the toxicity of agents or materials that have the potential to damage DNA.

nanomaterials (Guo, Singh, & Kleebe, 2006). Maynard (2006), Scheringer (2007), Scheufele *et al.* (2008), and Gatti and Montanari (2008) investigated the potential risks, health and environmental impacts of nanotechnology as a whole and/or of nanoscale particles in particular and therefore it can be assumed that these authors have directly acquired knowledge in one or more relevant areas as well.

What are the limits to knowledge by acquaintance? In a practical context, there are no limits. The limits, however, will start to show when it comes to retaining and, most importantly, updating the acquired knowledge. The most important question remains who can acquire what? Can a layperson acquire direct knowledge about nanotechnology, or to use one of the above examples, can a layperson acquire direct knowledge about the synthesis of nanomaterials, or the toxicological impacts of nanoscale materials on plant or animal life? In theory, yes, in practice, it is rather unlikely. In order to do so, a layperson would not only have to complete full scientific academic training, but then also specialise in the area of nanotechnology. If this were to happen, the layperson would not be a layperson any longer and, thus, be disqualified from the group of laypersons. In fact, the (former) layperson would very likely to become an expert in that chosen area. In this respect, every expert once was a layperson. What has changed is the acquisition of domain-specific knowledge and it is exactly that which has distinguished him/her from the laypersons. Table 13 shows who can possess knowledge by acquaintance and what lies outside this type of knowledge.

6.2.2 Tacit knowledge

Similar to knowledge by acquaintance, possessing tacit knowledge supposes direct contact to a specific subject matter. In addition, however, tacit knowledge accommodates human traits such as intuition and inference based on previous direct knowledge and observation. For instance, when Babu *et al.* suggest that their current findings "*raise the need for elaborate evaluations to ensure the safety of nano-silver*" (Babu, Deepa, Shankar, & Rai, 2008), then this can be attributed to the employment of tacit knowledge. It was due to their experiments that Babu *et al.* (2008) confirmed (what many others suspected) that nanosilver can be toxic, and in this instance, genotoxic to plant cells. Only by combining tacit knowledge with the recently directly acquired knowledge, were Babu *et al.* (2008) able to formulate additional research goals. In this case, it is the need to elaborate on the evaluations of the behaviour of nanosilver particles.

What are the limits to tacit knowledge in this context? First of all, everything that lies outside the domain specificity of the knower. Although this may seem obvious, in the case of Babu *et al.* (2008) it is actually fairly complex. In the context of their research project, the domain specificity lies within the ability to conduct laboratory experiments and to interpret results, and in the ability to understand and evaluate toxicological investigations. The researchers conducted an experiment by using the commonly known garden onion (*Allium cepa*), and, after germination, the roots were treated with varying concentrations of nanosilver. The subsequent investigation of the varying chromosome preparations followed procedures that are commonly accepted in science practice, for instance, by using "*techniques [that] had been developed for the detection of environmental mutagens*" (Babu, Deepa, Shankar, & Rai, 2008). Although the research conducted by Babu *et al.* was not nanotechnology research *per se*, that is, research that investigates properties or functions of nanoscale materials, the point of the research was to investigate risks that potentially may arise with regards to nanosilver particles. It was the tacit knowledge that the researchers possessed that led them to formulate statements, such as, current "[*s]tudies to justify the safety of nano particles in living systems are inadequate*" (Babu, Deepa, Shankar, & Rai, 2008), which in turn justified the reasons for conducting the research in the first place.

The tacit element of their study is therefore two-fold: Firstly, the scientist must have acquired the techniques to conduct the experiments and then perfected it by means of deliberate practice (see Chapter 3.3.1). The second element is that of the interpretation of the results. Without having prior and acquired knowledge of both laboratory experimentation techniques and domain-specific deduction skills, the formulation of the research question or hypothesis – in this case, whether the exposure of onions to nanosilver particles will lead to changes at a cellular level – would have not been possible. In addition to the evaluation of tens of thousands of cells and the subsequent statistical analysis, it was the researcher's tacit knowledge that allowed for the conclusion to be formed. The commonly known phrase 'you had to be there' perfectly describes the use of the tacit knowledge in this context and its implication when it comes to making recommendations.

6.2.3 Knowledge by description

To reiterate, knowledge by description refers to knowledge that can be obtained indirectly, without having to directly acquire it. Often this refers to factual information that can be obtained by the expert and layperson alike. One of the main problems with knowledge by description is that if it is not constantly being updated, it can easily lose its value and even become dangerously wrong. In the context of nanosilver, knowledge by description can be a number of things. For instance, anyone who has read Babu *et al.* (2008) now knows that onions treated with nanosilver show genotoxic effects. What is more, anyone reading a different article that reports on the experiments conducted by Babu *et al.* (2008) now know about the genotoxicity of nanosilver. What the receiver or the holder of this descriptive knowledge does not know is under which conditions this genotoxicity may pose a problem in the real world; that is, outside the laboratory. For this to happen, any reader of the article in which Babu *et al.* (2008) describe their experiments must have sufficient scientific knowledge to, first and foremost, understand the research and then, secondly, to put the research in context. If this were the case, then the holder of this knowledge would not only possess knowledge by description, but also knowledge by acquaintance.

The danger of only possessing knowledge by description, and that applies to the majority of people who are not experts, is when this particular type of knowledge is used to make recommendations, and, as mentioned before, when the descriptive knowledge is not being updated. Babu *et al.* (2008) investigated the effects of nanosilver on cell division in onions. And although Babu *et al.* (2008) have shown the potential genotoxicity of nanosilver in onions, this is not to say that this applies to all plant life, nor does it say anything about the impacts on animals or humans. Therefore, recommendations at this stage have to be limited until further evidence is produced.

6.2.4 Explicit knowledge

Explicit knowledge is the most indirect form of knowledge, and often equates to attributes of pure information (which, in turn, is nothing else than data that has been enriched by meaning). To reiterate, M. Polanyi (2000) referred to explicit knowledge as being everything that has or can be clearly stated. In the case of nanotechnology, or the example of nanosilver, the limits of explicit knowledge become very apparent. When looking at clear statements that describe nanotechnology in the sense of what can explicitly be known by laypersons and experts alike, one is mostly limited to its definitions, the descriptions of areas involved and high-level descriptions of current and future research. Although the study of Babu *et al.* is 'out there for everyone to find', to use another definition of explicit knowledge (Bock 2000), it should be reiterated that knowledge is only what is also understood (Lyre, 2002). It cannot be expected that a layperson understands the "*Effect of Nano-Silver on Cell Division and Mitotic Chromosomes*" (Babu, Deepa, Shankar, & Rai, 2008). Therefore, and although Bock's definition of explicit knowledge has been met, explicit knowledge in the sense of knowledge-intensive research remains expertise dependent for as long as parts of the audience to whom this type of knowledge is accessible has no means of evaluating or using it.

Both knowledge by description and explicit knowledge have one main downside; and that is, even if they are available, they require a certain amount of prior knowledge to add value to the non-expert, unless pure information gathering is the main aim of the use of these types of knowledge. The implications of this are shown in the analysis of Moe's approach and the use of external experts (see Chapter 6.4.)

In other words, laypersons require the help of expert knowledge holders to understand things that go beyond mere factual knowledge or headline information. Laypersons are able to pick up on the fact that nanosilver 'is not good' when exposed to onions, but the reasons why will elude them without possessing prior in-depth scientific knowledge. Furthermore, Babu *et al.* (2008) have conducted their experiments only with ordinary garden onions. Can one now conclude that the same result will apply to red onions (*Allium atrorubens*), shallots (*Allium oschaninii*) or garlic

(*Allium sativum*)? Although normally science needs to provide the proof to confirm such a statement, who is to say that every layperson, or the media for that matter, will adhere to scientific principle? This, in summary, describes another danger of both knowledge by description and explicit knowledge; that is, they often become limited to headline only information, although actually based on acquired knowledge. The problem is that without context, mere headline information has the potential to do more harm than good.

6.2.5 Policy Knowledge and Information

P.M. Haas (2004) argues that policy information and knowledge must be usable knowledge, that is, knowledge that can be used directly by policy-makers and politicians. In the same vein, Straf (2001) points out that it must be objective and based on evidence. In the case of nanosilver, usable knowledge for policy-makers and politicians is only knowledge and information that they are able to understand and use directly. Therefore, policy information behaves is a similar way to the characteristics of descriptive knowledge (Chapter6.2.3). As Lyre (2002) described by his sender-receiver analysis, information not only requires a sender, but also a receiver, who in turn, needs to understand the information. By using Babu *et al.* (2008) as an example, any policy-maker or politician who would read this research could know that onions treated with nanosilver show genotoxic effects. Similarly, any policy-maker or politician reading a different article that reports on the experiments conducted by Babu *et al.* (2008) would now know about the genotoxicity of nanosilver.

Also, similarly to descriptive knowledge, what the reader does not know is under which conditions this genotoxicity may pose a problem in the real world; that is, outside the laboratory. For this to happen, any reader of the article in which Babu *et al.* (2008) describe their experiments must have sufficient scientific knowledge to, first and foremost, understand the research and then, secondly, to put the research in context. Furthermore, there is now also a danger of only possessing descriptive knowledge. The negative aspects have been described in the analysis of descriptive knowledge (Chapter 6.2.3), that is, if this type of knowledge is used in order to make recommendations, and when/if this type of knowledge is not being updated. Although the potential genotoxicity of nanosilver in onions has been shown, nothing has been said whether that also applies to all plant life. Therefore, in order to make recommendations at this stage, further research evidence would have to be reviewed (in the case of nanosilver, it would have to be produced first, due to the novelty of the subject matter), and then accumulated and summarised in a wider body of knowledge.

When looking back at both P.M. Haas' and Straf's definitions of policy information, it becomes clear that pure scientific data, such as the aforementioned research publications by Oberdörster *et al.* (2007) or Babu *et al.* (2008), is **not** policy information. In other words, any detailed knowledge of the properties of nanoscale silver particles, their behaviour and reactions with other elements etc. is not policy information. This, then, also means that policy information must differ from both knowledge by acquaintance and tacit knowledge. That is, however, not to say that holders of both acquired knowledge and tacit knowledge cannot be part of the policy process. Quite the contrary, as experts, for instance, they can provide expert testimony to a wider policy audience for as long as their expertise is accepted as a contributing form of authoritative knowledge that is accepted by all involved (see also Chapter 6.3.2.1 – Options 1 and 2).

6.2.6 Comparing knowledge types

After comparing the five different knowledge types and establishing what can be known by whom and what cannot, the knowledge framework will now be used to determine how this translates to nanotechnology knowledge and to knowledge of nanotechnology risks. As it has been established in chapter 3, a number of the interviewed researchers felt uncomfortable answering questions about the environmental, social and legal aspects of nanotechnology, although all of the interviewed researchers were actively involved in nanotechnology research. By being scientists or technologist working on nanotechnology, but not on associated risks, a very distinct line is drawn with regards to acquired knowledge. In the case provided by Nanologue, researchers were nanotechnology experts, but not experts on nanotechnology risk. However, as the results presented in chapter 5 have also shown, the majority of researchers had an understanding of nanotechnology risk or ELSAs. In these instances, researchers also had descriptive knowledge of nanotechnology risk. Similarly, the civil society representatives also had somewhat of an understanding on nanotechnology risk due to their prior exposure to the subject matter. They were, however, not experts and had, therefore, no acquired expertise. If they did have acquired nanotechnology expertise, they should have been disqualified from the group of members of the civil society and should have been part of the expert group. When comparing these findings to the studies undertaken by other researchers with respect to public understanding and perceptions of nanotechnology, such as Currall et al. (2007) Kahan et al. (2007,2008) and others, then one can conclude that the public may have descriptive knowledge, if they have been exposed to it, but will not have any acquired knowledge. The table below provides a summary overview:

Knowledge type	Expert		Member of civil society		Public	
	NT	NT risks	NT	NT risks	NT	NT risks
Knowledge by acquaintance	Must have	Can have	Cannot have	Cannot have	Cannot have	Cannot have
Knowledge by description	Must have	Can have	Can have	Can have	Can have	Can have
Tacit knowledge	Must have	Can have	Cannot have	Cannot have	Cannot have	Cannot have
Explicit knowledge	Must have	Can have	Can have	Can have	Can have	Can have
Policy knowledge	Can have	Can have	Can have	Can have	Can have	Can have

Table 17: Comparing knowledge types

In this table, 'must have' refers to knowledge that is a given if the knowledge holder is to qualify for this particular group. For instance, in order to be an expert, a person must have acquired knowledge in at least one domain; for instance, nanotechnology. The risks of nanotechnology are, however, separate domains. 'Can have' refers to knowledge that a person is able to have or obtain, but is not a pre-requisite. For instance, a nanotechnology expert can have usable policy knowledge, but it is neither required nor is it outside the expert's ability. All that is said here, is that it is possible. 'Cannot have' refers to instances where holding this knowledge is outside the person's ability. For instance, if a member of the public has acquired the appropriate expertise, they will be discounted from this group and will instead be associated with the expert group.

Alternatively, one could also look at this comparison in terms of extremes: the best possible scenario and the worst possible scenario. The table below provides an example for a best possible scenario, taking experts and public as well as three selected knowledge types into account. The selected subject matter is nanosilver.

Knowledge type	Researcher		Public	
	NT	NT risks	NT	NT risks
Knowledge by acquaintance	Does have Example: Nanosilver	Does have Example: Biomagnification of nanosilver	Does not have	Does not have
Knowledge by description	Does have Example: Nanosilver	Does have Example: Biomagnification of nanosilver	Does have Example: Nanosilver	Does have Example: Biomagnification of nanosilver
Policy knowledge	Does have Example: Nanosilver properties and acceptable concentration levels	Does have Example: reason why biomagnification requires action and what the results of inaction would be	Does have Example: Nanosilver properties and acceptable concentration levels	Does have Example: reason why biomagnification requires action and what the results of inaction would be

Table 18: Best case scenario of available knowledge of nanosilver

The above table differs from the previous one, as it does not intend to identify what can be known, without specifying whether a person actually does hold that knowledge. Instead, this table shows what a person does know while staying within the scope of the definitions of the respective knowledge types. In the example above, an expert of nanosilver is also an expert of the risks of nanosilver while also possessing sufficient usable policy knowledge. All that is being said here is that it is possible that an expert can be the holder of all three knowledge types while also being an expert in two domains: nanotechnology and the risks of nanotechnology. For the public, the situation is similar, with one exception. As the definition of an expert does not allow for it, a member of the public, who is by definition a non-expert, does not have knowledge by acquaintance of either nanotechnology or nanotechnology risks. However, this does not exclude the member of the public from having excellent descriptive knowledge and also usable knowledge for policy-making. Considering that the above example is an extremely unlikely scenario, questions need to be asked and answered with regards to how expertise can be transferred, how usable information can be made available to the policy-maker and how the public can be included. The following chapter analyses the recommendations and recommended actions from the researchers and from the members of the civil society as well as those made by Nanologue.

6.3 Applying the knowledge framework to policy recommendations

Nanologue's study of the ELSA of nanotechnology concluded with a number of significant findings. Two of them shall be reiterated here: First and foremost, it stresses that a distinction needs to be made between an expert in the area of nanotechnology and an expert in the field of the ELSA of nanotechnology. Secondly, both the attending researchers and the members of the civil society agreed that there is too much negative headline information out there. None of that, however, is surprising when applying the knowledge framework (see Chapter 3.6).

This section aims to apply the knowledge framework introduced in Chapter 3.6 to a number of policy recommendations made in research and publications that have been used in previous chapters. The main aim is to investigate whether the policy recommendations, when tested against the knowledge framework, are as viable as the authors assume, and, if not, to introduce alternative recommendations that can be formed based on the research conducted. Before going into detail, a quick discussion will highlight what the problems of policy recommendations are and what their purpose is.

Majone argues that "*policy problems are not textbook quizzes, they carry no guarantee that there always exist correct solutions against which analytic conclusions may be checked*" (Majone, 1989, p. 65). The same needs to be said about policy recommendations. Haas and Springer (1998) suggest that although available information and outcomes of policy research carry weight within the realm of complex decision-making, the main aim remains to reduce uncertainty in public decisions, to increase clarity and consistency of decision makers' understanding, to bring new perspectives and understanding of public problems and responses as well as to improve the quality of public debate (Haas & Springer, 1998). Moreover, this needs to be put into context when then looking at what policy information is and how actors behave around it in different circumstances, that is, an actor's dependency on the extent of their familiarity with a particular policy problem.

In the case of nanotechnology, and for that matter, any other new and just emerging technically complex subject matter, the likelihood that policy-makers or politicians are familiar with it is very small. As Oh and Rich (1996) pointed out, policy-makers tend to behave differently when confronted with an unfamiliar policy problem. Instead of using their 'normal' and familiar information sources and agencies, policy-makers are forced to look beyond their familiar circles in order to get the information required. One of the direct results of this is that policy-makers, therefore, not only use much more information than normal in order to mitigate their unfamiliarity, but also potentially stray from their expected policy-decisions. Unlike with familiar policy-problems, which in turn, often "*reinforce decision-makers' positions on the problems*" (Oh & Rich, 1996, p. 12), unfamiliarity increases the information need.

6.3.1 Recommended actions and recommendations - Nanologue

The Nanologue group lists several actions as being recommended by the participating researcher and the members of civil society as well as generic and specific recommendations. In addition to Nanologue's recommendations, two particular types of recommended actions shall be tested in more detail:

- information and educational campaigns aimed at the public,
- actions for governments.

6.3.1.1 Recommended actions by researchers

Information and educational campaigns aimed at the public are a growing concern amongst scientists, Nanologue reports. Although there was general agreement about the importance of these campaigns, there was concern about conflicting messages that, in the long term, may do more harm than help. Furthermore, the complexity inherent in knowledge-intensive technologies, such as nanotechnology, comes at a price. The researchers argued that "*to be understood by the general public information campaigns require a simplification of content, which in itself may cause a problem* *given the complexity of NT*" (Nanologue, 2006, p. 62). Further issues mentioned in this regard were as follows: the public may not even realise which products have been enhanced through the use of nanotechnology; the choice of information channels is a challenge in itself, as "*information is always considered not sufficient. The challenge is to choose the right communication channel to assure that important and balanced information is perceived*" (Nanologue, 2006, p. 63). Another action point mentioned by several experts was that "*the responsibility to inform the public lied with public science and industry that should more actively present their findings on conferences and work closely with media*" (Nanologue, 2006, p. 63).

Actions for three additional groups, namely journalists, workers, governments and policy-makers, were listed specifically. Journalists were perceived as information gatekeepers and, therefore, the education of journalists must play an important role: "*If journalists don't feel comfortable with the topic, how can we expect the media coverage about NT to be positive?"* (Nanologue, 2006, p. 63) was a question asked by one particular researcher. The role of the workers needs to be highlighted in information campaigns, as workers may potentially be exposed to nano-particles. Finally, and similarly to the case of journalists, government and decision-makers require education and political advisory on nanotechnology.

Actions to be taken by government are the second point to be discussed. Here, four main categories have been identified by the researchers: provision of funding, monitoring/governance of research, information and market-based instruments. Two of them will be discussed further: funding and information.

In addition to providing funding for both basic and application-based research, it was suggested that the role of governments should extend to "*better steer research activities towards the most important issues, e.g. risk assessment of nanoparticles, recycling option for materials containing nano-particles, and encourage the formation of multidisciplinary teams comprising of researchers, technologists, legal experts, experts for public perception and ELSA, business developers and "to a certain degree" politicians*" (Nanologue, 2006, p. 65). Another issue that has been highlighted by the researchers is the tendency to declare research as nanotechnology related in order to increase the chance for funding, even though much of that research does not fall into the category. Here, as the researchers suggested, government must improve on monitoring funding mechanisms.

With regards to information, the recommended action is that "*governments should take a lead on public outreach and information about ELSA and NT and participate (again through funding) to structure and balance the public debate*" (Nanologue, 2006, p. 65). One suggestion mentioned was that administrators and politicians should stay informed about nanotechnology developments. However, due to the lack of specificity of what was meant by 'information', this recommendation falls short of what is was supposed to deliver. Once can assume that, when governments are asked to deliver information to the public, it refers to descriptive information. This is problematic for two reasons. Firstly, it contradicts current trends of corporate vs. public funding of nanotechnology (see Chapter 4.3). Corporate funding has already surpassed public funding. Without explaining how governments can obtain corporate knowledge, this recommendation is therefore limited to what governments can control via the funding they provided. And even here, it is not guaranteed that governments can actually function in that capacity due to a lack of expert knowledge. The knowledge framework has established what can be known by whom. Governments do not have their own nanotechnology experts and, least of all, experts in the health and environmental related risks. Here, the overall available body of knowledge on the subject matter also plays a role. As it has been shown, there is a profound lack of available expertise of the health and environmental impacts of nanotechnology (see Chapter 4.6). Secondly, this recommendation fails to provide insight into what instruments are to be used by governments to 'balance' the public debate. When compared to the findings by Kahan *et al.* (2007, 2008) and Currall *et al.* (2007), who have provided compelling evidence as to how public perception on nanotechnology is formed and influenced by the provision of additional information, then it needs to be said that the subject of informing the public is too complex a topic that could simply be addressed by suggesting that governments should perform this function. For this recommendation to be fruitful, more basic research into the understandings of public perceptions of nanotechnology is required. In addition to obtaining qualitative and quantitative data of public opinion, there is also need to include theoretical work that establishes models based on values, norms, attitudes and other pre-dispositions the public may have. Thus, Currall argues that a better and deeper *"understanding of predictors of public perceptions, scientists, policymakers and businesses will therefore be better positioned to anticipate trends that will dictate how the public reacts to new scientific developments and commercial products based on nanotechnology*" (Currall, 2009, p. 80) is required. Unfortunately, such predictors were not established by the Nanologue study; also because of Nanologue's substitution of public opinion with that of their selected group of members of civil society, which, in itself, limits the usability of the obtained data. Furthermore, Currall (2009) suggests that social scientists should translate "*technical research findings into language that is directly useful to others*" (Currall, 2009, p. 80). This view, however, is quite different from what Nanologue suggest.

6.3.1.2 Recommended actions by members of civil society

Nanologue argues that in general, the actions recommended by members of civil society mainly focus on mitigating risks than on maximising the benefits of nanotechnology. Thus, the structure of recommended actions is somewhat different when compared to that of the researchers. The recommended actions that will be discussed here further are:

- Addressing risks
- Engaging scientists in a dialogue
- Taking the dialogue to the public and framing the Information and education campaigns

Number one action was the recommendation to prevent a nanodivide; that is, preventing an "*increasing technological gap between developing and industrialised countries*" (Nanologue, 2006, p. 23). Other concerns covered by the term nanodivide are: concentration of powers and access to nanotechnologies (for instance, by means of high costs of potential medical treatments) and access within and between societies (Nanologue, 2006). The actions call for NGOs and governments to "*take a lead in initiating education on the issue and starting a public debate about the role of technology in our society*" (Nanologue, 2006, p. 67). The second recommended action within the risk category is on toxicity of nanotechnology and nanoparticles. In particular, information sharing on toxicity and the transparent sharing of knowledge by the business are recommended actions. The third and final point is to prevent a 'nano-bubble': "*Stakeholders involved in the development of and communication on nanotechnologies should beware of fuelling the "nano-hype" to an extent that causes unrealistic expectations of the technology from consumers*" (Nanologue, 2006, p. 67). Here, the idea is to publicly discuss what nanotechnology can deliver in order to prevent social disappointment as well as financial risk.

Taking into account that there is a general hesitancy amongst scientist towards supporting public engagement due to lack of time and support, the members of civic society proposed the following actions:

- Engagement on and communication of ELSA should be a condition of all grants and there has to be a move "beyond publishing" to get away from just publish or perish. Those in management positions should also provide encouragement to staff to work on ELSA;
- Ensure that scientists have training in media, communication and ethics;
- There should be independent funding for ELSA communication and funding for dialogue between Government, business and wider society;
- The science education system needs to be updated to integrate discussions around science and society (Nanologue, 2006, p. 69).

The final point of recommended actions that will be discussed here is the dialogue with the public and the framing of information and education campaigns. Recommended actions are to train the public in popular science and science literacy in order to encourage public involvement in the dialogue. Furthermore, it was suggested that it might help if practical aspects of nanotechnology are used to explain benefits for society. A main issue in this area, however, remains the correct use of mass media. In this regard, Nanologue argues, the correct framing of the issues plays a vital role. Again, focussing on the benefits of nanotechnology, for instance on specific problems and applications that have societal benefit, has been recommended as well as preventing the focus on risks. A positive example mentioned here was that of sustainable development. "*It is essential that this framework be used as early as possible in the development process*" (Nanologue, 2006, p. 71) is the final recommended action from the group of members of civil society.

6.3.1.3 Nanologue's recommendations

Nanologue recommends that there should be an ongoing discussion about the risk and benefits of nanotechnology that runs in parallel with technological advancements. This discussion should focus not on risks, but on a vision of using nanotechnology for sustainable development in order to maximise benefits and minimise risks. This vision should also aim to attract media attention and focus on technological potential. Then, contextualisation is required, as some of the currently advocated technologies are actually not nanotechnologies in the narrower sense. Thus a differentiation between 'real' nanotechnologies and those that exist only under the mantle of nanotechnology (for instance, in order to attract funding) is required. Another aspect of contextualisation is to focus on what would benefit society: "*We might not need NT-golf balls, but we might need NT based energy systems or medical applications*…" (Nanologue, 2006, p. 73). Similarly, contextualisation is required when it comes to assessing risks. Risks should be discussed for particular nanotechnologies, instead of being "*lumped together as "risks of Nanotechnology" in the public discussion, making a public backlash more likely*" (Nanologue, 2006, p. 73). The same applies to non-expert decision-makers in politics, business and society.

While drawing on previous experience (for instance, in the areas of biotechnology or GMO), Nanologue recommends that any public dialogue needs to be as transparent and open as possible. "*The discussion on GM raised serious questions mainly but not exclusively about corporate transparency in particular, and this must be overcome*" (Nanologue, 2006, p. 74). At the same time, however, a public information overload should be avoided, as too much information could lead to confusion and disengagement and thus achieve the exact opposite of an open dialogue. As a final point with regards to open dialogue, Nanologue argues that there must be a clear distinction between fact and fiction in the public debate. Hence, there is a need to stress the current state of R&D and also a need to illustrate potential future developments, timeframes and technological advancements that are achievable and realistic.

The final area of recommendations by Nanologue is that of access to information. The majority of the above recommendations are put into jeopardy when access to information is a serious issue. The lack of knowledge of nanotechnology and that of the ELSAs of nanotechnology (see also Chapter 4.5) cannot solely be attributed to the complexity of nanotechnology, as a lot of information is already 'out there'. However, it was felt that the information is neither available in one central place nor is it always accessible. Thus the final recommendations are as follows:

- A 'clearing centre', hosted by an institution with high social legitimacy, could be set up;
- Activities could be initiated that involve the general public via museums or science centres for example;
- Producers of products that contain NT-components should inform and engage with retailers;
- Labelling of NT products has been suggested, while others were cautious about this. A public discourse on this issue might be needed;
- Journalists and the media should be directly targeted with information both about benefits and risks (Nanologue, 2006, p. 76)

6.3.2 Assessing the recommended actions and recommendations

When reviewing the above recommendations, no matter whether they were formed by the researchers, by the members of civil society or by the Nanologue group themselves and no matter whether the recommendations focus on assessing nanotechnology related risks, funding or involving the public, what becomes obvious is that the key to each of those areas is information, or better still, data, information and knowledge. What matters is not only know-how, but also know-what and know-who. What matters is the data, the information and the knowledge available to experts and what is not available to the 'have nots'. Possibly more than ever before, it matters what can be known by whom and what cannot. The table below (in no particular order) summarises the main recommendations from Nanologue (see also Chapters 6.3.1.1 -6.3.1.3), and also reiterates some of the commonly named problems.

List of commonly named problems	List of recommendations/actions
• conflicting messages • complexity • public's ability to understand • simplification of content • contextualisation • relating risks to particular nanotechnologies • information sharing and transparency • media focussing on negative headlines	• simplification of content • contextualisation • education and political advisory • administrations and politicians to stay informed about nanotechnology developments • governments should take a lead on public outreach and information • to use funding to structure and balance the public debate • information sharing on toxicity and the transparent sharing of knowledge by the business • communication of ELSA should be a condition of all grants • scientists have training in media, communication and ethics • science education system needs to be updated • train the public in popular science and science literacy • public dialogue needs to be as transparent and open as possible • avoid public information overload • focussing on the benefits of nanotechnology • a clearing centre or central place that hold information for all • correct use of mass media • targeting journalist and the media with information both about benefits and risks

Table 19: Summary of Nanologue's recommendations and actions

The above table is the result of analysing Nanologue's research and by grouping it according to items that have been identified as issues by the participants of Nanologue's studies and by comparing it to recommendations made by both the participants of Nanologue's survey and by Nanologue itself. A number of contradictions can be seen. Although it shows that no matter whether the recommendations are aimed at governments, policy-makers, the industry or experts themselves, it all comes down to information and knowledge. What is does not show is what has been established in the knowledge framework, that different types of information and knowledge require different approaches, have different target audiences and are often dependent of specialists in order to interpret meaning. For example, the table shows that some of the recommendations are, at the same time, also problems: simplification of content is one example, contextualisation another. Thus, the public's limited ability to understand knowledge-intensive and complex technologies is a challenge for all involved. Neither the industry nor governments can lie back and simply wait. Therefore, a closer look at these issues is required.

6.3.2.1 Assessing problems

A number of the recommendations are, at the same time, problems in their own right. For instance, simplification of content; that is, making outcomes and findings of nanotechnology research and nanotechnology-related risk research available to the public in a manner that it can clearly be understood by the public without the need to have to have a science education background. On the one hand, simplification of content has been named as one of the major issues relating to knowledge-intensive technologies, yet on the other hand, it is part of the recommendations to overcome the exclusiveness of science research. How can one bridge that gap? Nanologue presented simplification of content as both part of the problem and part of the solution, yet Nanologue failed to illustrate how this can be achieved. By applying the knowledge framework (see Chapter 5.2, Table 13), one can classify the problem as knowledge by acquaintance (or tacit knowledge) specific and the solution as a matter of providing descriptive or explicit knowledge (or information). Both classifications of knowledge, however, as this thesis has shown, target different audiences. In other words, pure science and technology research targets other scientists; peer-reviewed publications are not only not aimed at the public, but are also often not accessible by the public, which in turn, poses another problem – accessibility. What are options of transforming expert knowledge into publicly understandable information? Edwards argues that "*technical knowledge invariably declines into technocracy unless we also* *invest in the knowledge-making and interpretive capacities of the broadest range possible of the population*" (Edwards, 2010). Thus, two options shall be discussed, including their obstacles.

Option 1 – Let the expert be the informer

The first option would use an expert to overcome the problems of simplifying content. Here, an original participant of research would, in addition to his/her research publication, also write a popular scientific version of the research outcomes and, if applicable, their potential implications. The main advantage of this option is that first-hand knowledge could be passed onto a larger audience. The obstacles to this approach are threefold:

First, this approach would require the experts to have the relevant communication skills. As shown by the use of expert testimony in court cases, not all experts have the ability to convey their research findings in ways that make them understandable, and henceforth, usable by the general public (Page & Lopatka, 2004).

The second obstacle is that a number of experts work solely on individual components or aspects of a bigger problem, thus "[*i]t is misleading to think of the expert as being perfectly clear-headed about all aspects of their domain*" (Firlej & Hellens, 1991, p. 23). As shown with the case of the potential genotoxicity of nanosilver in onions (Babu, Deepa, Shankar, & Rai, 2008), researching individual components does not automatically lead to wider conclusions. Thus, even if this information were made available, it would not paint a complete picture for the public, and the result of public reactions may easily turn into a negative one.

The third obstacle is that of making experts release descriptive versions of their research to the public. Nanologue, for instance, suggested that funding should be tied to public participation (Nanologue, 2006). Although the ideas sound compelling at first, in reality this is a larger issue in itself, as (1) this could be enforced for public funding only and (2) it immediately brings the first two of the above mentioned obstacles on the table. Furthermore, should public funding really discriminate against researchers who may not have the skills to communicate outside their domain? And what if the release of partial information, that is, information that relates only to components or small areas of larger research issues, leads to premature panic or other kind of negative public reactions? Again, the research of Babu *et al.* (2008) can be used to illustrate an example: showing the potential genotoxicity of nanosilver in onions does not automatically mean that nanosilver has genotoxic properties that can negatively affect all root vegetables.

In addition to the three obstacles above, one needs also to take the corporate sector into account. As shown in Chapter 4.3, corporate funding exceeded public funding for the first time in 2007, thus rendering Nanologue's recommendation obsolete for the majority of research carried out when taking the use and enforcement of patents and intellectual property rights into account.

Option 2 – Use knowledge elicitation

As opposed to Option 1, knowledge elicitation does not rely on the original expert or author to issue/write a version of his/her research that would be understandable to the public. Knowledge elicitation, which is the process of retrieving knowledge from a human expert (Hoffman, Shadbolt, Burton, & Klein, 1995), uses knowledge elicitors to extract expert knowledge (Firlej & Hellens, 1991). Knowledge elicitors are experts in their own right, or, in other words, are knowledge elicitation experts. The purpose of knowledge elicitors is to understand an expert's skill, to document domain-specific knowledge and to structure and prepare the elicited content for further use (Firlej & Hellens, 1991). The process is based on two main components or steps: creating views and layering the knowledge. Creating views is used to represent smaller areas of the knowledge domain (unless the experts' domain is very small) and then layering comes into play in order to break elicited content into smaller components. Here, the aim is to "*move downward from general high level characteristics, through successive levels of greater and greater detail until the required level of detail has been achieved…"* (Firlej & Hellens, 1991, p. 156). Knowledge elicitation is normally carried out by using varying interview techniques, depending on subject matter and circumstances, followed by an analysis phase and a review phase. The latter two aim to prevent the knowledge elicitor either adding or misinterpreting domain-specific knowledge.

The main advantage of using knowledge elicitation is to obtain first-hand knowledge that often would not be available otherwise. In addition, and depending in the skill set of the knowledge elicitor, additional information may be revealed of which the domain knowledge holder may have not been aware (Gourlay, 2002, 2004; Polanyi M., 2000; Firlej & Hellens, 1991). Furthermore, obtaining domain-specific knowledge by means of knowledge elicitation can be targeted, thus allowing governments, institutions and organisations to obtain specific knowledge and information as per their needs.

The main obstacles are cost, availability of knowledge elicitors and access. Firlej & Hellens provide some insights into the costs of knowledge elicitation. If, for instance, a total of ten hours (i.e 5 x 2 hours) of interview time is required, then the total amount of man hours, by taking preparation time, time for transcripts, and time for the analysis and review periods into account, will amount to 245 hours, which equals seven weeks (Firlej & Hellens, 1991). The second obstacle is availabilty of knowledge elicitors. In short, there are not many knowledge elicitors available, as this is an expertise in itself. In other words, there is a reason why the term knowledge elicitor is not a well known job title or description and why the field has not received much recognition within academia or in the corporate world. The majority of research was either carried out in the 1990s when Knowledge Management was a popular subset in Business Studies and Management Sciences (Hoffman, Shadbolt, Burton, & Klein, 1995), or as part of research focussing on (computerised) expert systems (Firlej & Hellens, 1991). The final obstacle to knowledge elicitation is access. Similar to the observation mentioned for Option 1, when the majority of research is funded by corporations, then access becomes an issue due to the potential enforcment of intellectual property rights.

Considering the above obstacles of Option 2, there remains the question as to whether knowledge elicitation is a viable alternative to Option 1, which, as has been shown, comes with its own issues. The lack of academic research and literature on the topic of knowledge elicitation notwithstanding, there is no easy answer to the question. Taking the current levels of public understanding of nanotechnology into account (Currall, King, Lane, Madera, & Turner, 2006; Kahan, Braman, Slovic, Gastil, & Cohen, 2008;

Nanologue, 2006), the dire need for actions and options, however, becomes clear. Nanologue (2006) suggested to link public partcipation to the availability of funding. Although it has been shown that this is an issue when linking it to experts directly (see Option 1), linking knowledge elictitation to the availability of public funding could be a viable alternative, as it does not discriminate against experts that lack personal communication skills. Furthermore, public funding often involves focussing on specific target areas and topics (see EUs Framework Programmes), thus obtained information can be structured and distributed accordingly.

6.3.2.2 Assessing recommendations

The use of funding to structure and balance the public debate as one of Nanologue's recommendations has been discussed above. Despite the discussed obstacles to this, Nanologue are not alone with their recommendation: "*With respect to the future, government funding should be provided for interdisciplinary research centres that promote collaborative research among physical scientists, engineers and social scientists*" (Currall, King, Lane, Madera, & Turner, 2006, p. 155). Currall *et al.*, however, recognise the limits and explicitly refer to government funding. The next point raised by Nanologue is to provide training in media and communication to scientists. As Option 1 has shown, this may be perceived as discriminatory by some scientists and, bar regulatory changes and subsequent enforcement, it may only be applicable to publicly funded research. In other words, this recommendation relies on voluntary participation by scientists and despite its good intentions, the expected positive outcomes of this are, at this point in time, pure conjecture.

The next two recommendations that need to be assessed here are the suggested correct use of mass media and the targeting of journalists and the media with information about benefits and risks. Again, Nanologue do not provide any specifics as to how this can be achieved. There is no doubt, that framing plays a vital role. However, what are the chances that positive framing with emphasis on the positive side of nanotechnology will dominate the public debate? Realistically, the chances are not good. Why? Nanotechnology, as well as a number of other new and emerging technologies, such as Genetic Engineering or Synthetic Biology, are simply too good an example for negative, 'doom and gloom' headlines. When considering how the public informs itself by breaking down news coverage by quality and distribution, or circulation, then the likelihood of an all-positive debate becomes slim. Nonetheless, a closer look into how the public informs itself should reveal some insight. Just to show an example, the UK and German newspaper markets shall be compared to illustrate a high-level view of how the public in both countries sources its main print-based information.[37] For example, Table 15 below shows newspaper circulation in the UK by quality and numbers:

Newspaper	Year	Circulation	Type
United Kingdom			
The Sun	2006	3,148,700	Tabloid
The Daily Mail	2006	2,340,255	Tabloid
Daily Mirror	2008	1,494,000	Tabloid
Daily Telegraph	2008	874,000	Broadsheet
Daily Express	2008	745,000	Tabloid
Daily Star	2008	726,000	Tabloid
The Times	2007	618,160	Broadsheet
The Guardian	2007	355,750	Broadsheet
The Independent	2008	240,503	Broadsheet
Financial Times (UK)	2007	133,665	Broadsheet
Germany			
Die Bild	2008	3,345,468	Tabloid
Süddeutsche Zeitung	2008	457,353	Broadsheet
Frankfurter Allgemeine Zeitung	2008	387,064	Broadsheet
Die Welt	2008	279,004	Broadsheet
Frankfurter Rundschau	2008	161,867	Broadsheet
Financial Times Deutschland	2008	104,101	Broadsheet

Table 20: Tabloid and broadsheet circulation in the United Kingdom and Germany (Tryhorn, 2008; WAN, 2008)

This simplified view of the print market in both countries shows that in the UK, tabloids outsell broadsheets by a roughly 4:1 and in Germany by roughly 2.5: 1. Considering that the reach of each newspaper is three times as high as the number of sold copies, at any given day, approximately 25 million people in the UK obtain their print-based information from tabloids, and slightly more than 10 million people in Germany. Thus, recommending the 'correct use' of mass media as well as targeting journalists and the

[37] It shall be by no means suggested here that this study is representative for the entire media market. In order to achieve such a view, radio, TV and the full spectrum of the Internet as news resource needed to be investigated. The purpose of investigating the print and online newspaper market is solely to get a better understanding of some of the potential issues involved.

media with information about benefits and risks of nanotechnology is a moot point. The University of Plymouth conducted a survey of British newspapers and their coverage of nanotechnology between April 2003 and June 2004. The press coverage of nanotechnologies at that time was limited to a small number of 'elite newspapers' (Petersen, 2006), which, as Table 15 shows, have a fairly limited circulation in comparison to tabloids. The number or appearances of news coverage on nanotechnologies was as follows: The Guardian (24%), The Times (19%), The Financial Times (14%), The Independent (10%), and The Daily Telegraph (7%). Tabloids, or mass-market newspapers, reported relatively scarcely on nanotechnology during the survey period. The News of the World was the only paper not to feature any articles containing the keywords nano or nanotechnologies (Petersen, 2006). The study also showed that a "*significant amount of the coverage was not authored by a health, science or environmental correspondent or editor - writers who are likely to have at least some knowledge of the area. Indeed, 57% of items in the sample were by "general" or "other" correspondents*" (Petersen, 2006). When considering Petersen's findings about who authored these articles, then Nanologue's recommendation to target the media with information about benefits and risks of nanotechnology seems a good idea at first sight. However, it also begs the question whether such endeavour would rather further these trends, as one might argue that the journalistic work involved in writing science-based news and articles can now be left to general correspondents, since detailed information has already been provided. In addition, the above figures show that the reach of news coverage of nanotechnology is very limited, which in turn questions whether the media are the right vehicle in the first place? This view is confirmed by Scheufele *et al.* (2007) who argue that the levels of attention that nanotechnology and its risk have received in mass media have been low. A quick search for the term nanotechnology on the most popular tabloids' websites revealed the following:

The Sun listed 8 stories in total between 2004 and 2008; The Daily Mail listed 46 stories between 2000 and 2008 and the Daily Mirror listed 11 stories between 2003 and 2008. To make things worse, the results of the websites' search engines listed everything that contained the word nanotechnology, from film news to celebrity news. Similar to

Petersen's observations made when reviewing the results of the UK broadsheets (see Figure below); the news coverage can be classified as either neutral (balanced), positive (accurate, beneficial) or negative (inaccurate, sensationalised, detrimental).

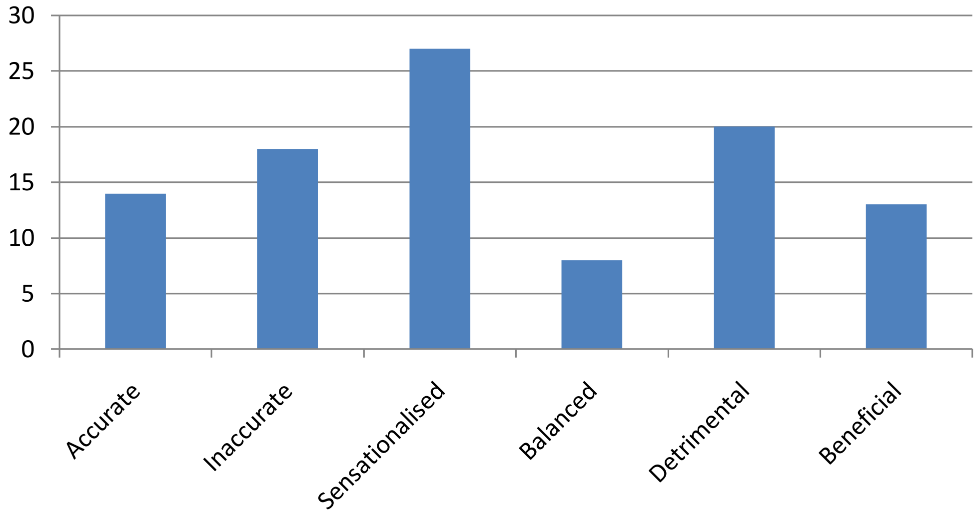

Figure 17: Broadsheet coverage of nanotechnology (Petersen, 2006)

The Sun's coverage contained four sensational and one neutral headline (the other three stories were actually not related to nanotechnology). The Daily Mail contained nine outright negative headlines[38] and 17 sensationalised headlines[39]. The few positive and accurate messages that were reported by The Daily Mail had been sensationalised. The results of the Daily Mirror were comparable to that of The Sun.[40] All in all, this paints a dire picture, not only on the coverage of nanotechnology in general, thus confirming the observations made by research carried out on the public's understanding of nanotechnologies (Kahan, Slovic, Braman, Gastil, & Cohen, 2007; Currall, King, Lane, Madera, & Turner, 2006), but also on the 'correct use' of the mass media as suggested by Nanologue. The main problem with this recommendation is not that it does conflict with current trends, as shown above, but that it lacks applicability when taking the news market into account. The scarcity of news coverage as reported

[38] Outright negative headlines are viewed as ones that mainly play on the negative and speculative risk side of nanotechnology. For example: "Alert over the march of the 'grey goo' in nanotechnology Frankenfoods" or "The beauty creams with nanoparticles that could poison your body".

[39] For example: "Revolutionary device 'can detect bird flu in 30 minutes" or "Could tiny golden bullets kill cancer?".

[40] Personal search carried out by entering the word 'nanotechnology' in the provided search function of the website of The Sun (www.thesun.co.uk), The Daily Mail (www.dailymail.co.uk) and the Daily Mirror (www.mirror.co.uk). Search carried out on January 20, 2008.

by Peterson (2006), and results found by searching the websites of the tabloids need to ask the validity of this recommendation in question. Without judging the quality of nanotechnology coverage in tabloids, one fact remains: the news corporations that own these newspapers run a business, and the realm in which they operate is a free market. Simply put, both in Germany and in the UK, tabloids outsell quality newspapers by far and this is simply due to public demand. Nanotechnology, and especially positive news about nanotechnology do not sell newspapers.

By applying the knowledge framework and the findings above to the recommendations made by Nanologue, then a number of issues become apparent (see Table 16 below). Six of the recommendations are dependent on the transformation of tacit knowledge into explicit knowledge (or knowledge by acquaintance into descriptive knowledge). The obstacles to this have been shown in the discussion of Options 1 and 2 (see Chapter 6.3.2.1). Four recommendations are dependent on research being publicly funded (also see the discussion of Options 1 and 2 in Chapter 6.3.2.1), thus rendering the recommendation for the majority of current research obsolete. The final four recommendations are being made moot due to the realities of the media market, as discussed in this chapter. What remains is the question as to whether such a harsh view on the quality of the recommendations made by Nanologue diminishes the quality of the research carried out, and subsequent questions about the value of Nanologue’s study?

List of recommendations/actions	Dependency or issue
simplification of content	transformation of explicit into tacit knowledge
education and political advisory	transformation of explicit into tacit knowledge
administrations and politicians to stay informed about nanotechnology developments	transformation of explicit into tacit knowledge
governments should take a lead on public outreach and information	transformation of explicit into tacit knowledge
to use funding to structure and balance the public debate	only applicable to publicly funded research
communication of ELSA should be a condition of all grants	only applicable to publicly funded research
scientists have training in media, communication and ethics	if at all, only applicable to publicly funded research
science education system needs to be updated	transformation of explicit into tacit knowledge
train the public in popular science and science literacy	transformation of explicit into tacit knowledge and news market based on free market values
focussing on the benefits of nanotechnology	news market based on free market values
a clearing centre or central place that hold information for all	only applicable to publicly funded research
correct use of mass media	news market based on free market values
targeting journalist and the media with information both about benefits and risks	news market based on free market values

Table 21: Applying the knowledge framework to selected recommendations

First of all, the importance of Nanologue's research cannot be stressed enough. Nanologue's research has purposefully been chosen to serve as a case study for this thesis, as it combined expert opinion with non-expert opinion and because it was the first study carried out on such a major scale. Also, it linked researchers from four different institutes across Europe, within four different countries (Germany, Switzerland, the UK and Italy). Furthermore, Nanologue's approach focussed on both nanotechnology and the ELSAs of nanotechnology, thus providing a unique opportunity to gain expert and public insight into the current debate (see Chapter 4.5).

Where did things go wrong then? Actually, they didn't. Nanologue's recommendations are on a par with the majority of (policy) recommendations given by social scientists. In fact, they are fairly representative of what so far has been the 'standard mode' of providing recommendations. This 'standard mode' can be defined by the commonly-used wide spectrum that is applied to recommendations without actually being specific. In other words, currently, recommendations such as 'scientist and society should work together' or 'the public should be more involved' are very much standard recommendations made to governments or policy-makers. The point that shall be made here is that the use of scientific knowledge and expert opinion needs to change, going forward. As part of a panel discussion organised by the Royal Society, Ian Gibson put it as follows: "*in terms of science and how we use the knowledge of science in decision-making and policy-making has a long, long way to go yet*" (RSA, 2004, p. 10).

The ESRC (2007) summarised explicit as well as implicit social and economic implications of nanotechnology after having carried out an extensive literature review. Based on these findings, a number of recommendations can be identified. Although a number of researchers have identified ethical concerns with regards to nanotechnology, not many have specifically identified the need to involve the public. Although, MacDonald (2004) stresses the need for "*greater synergy between scientists, society and corporations"* (ESRC, 2007, p. 38), Williams-Jones (2004) implies that meaningful public engagement is essential, Sweeney *et al.* (2003) ask for the involvement of the public, Wolkow (2004) highlights substantial societal implications, Sheremeta & Daar (2004) ask for the investigations of public perception and engagement, Schummer (2005) suggest that "*nano-scientists and social scientists are best placed to comment on social and ethical implications*" (ESRC, 2007, p. 45), and The Royal Netherlands Academy (2004) suggests that there "*are lessons to be learned from the GM controversy, and the introduction of new technologies should be carefully managed*" (ESRC, 2007, p. 43). There was no mention of the potential difficulties the public or policy-makers might have to understand nanotechnology. The suggestions made in this thesis with regards to both the knowledge-intensity and complexity of nanotechnology have not been mentioned once as being an issue.

Similar to the findings of the ESRC (2007), and again without providing the 'how', Maynard (2006) suggests developing "*communication activities that enable technical information to be summarized, critiqued and ultimately synthesized for various interested parties, including decision-makers and consumers. The advent of the Internet provides an ideal venue for such activities and we encourage its use in communicating with the end-users of risk-based science*" (Maynard, 2006, p. 269). The first suggestion is echoed by Currall *et al.* (2006) as well as Bainbridge and Rocco (2005) (see below), who, however, are more specific in terms of who should take on such a task. The latter recommendation is similar to that of both Nanologue (2006) and Currall *et al. (*2006), who suggested using clearing-houses as a means of distributing information on nanotechnology to the public. Currall *et al.* (2006) as well as Bainbridge and Rocco (2005) suggest making use of respected institutions, such as the Royal Society and Royal Academy of Engineering in the UK and the National Academies in the United States. The Royal Society agrees with these recommendations:

> We recommend that the research councils build on the research into public attitudes undertaken as part of our study by funding a more sustained and extensive programme of research into public attitudes to nanotechnologies. This should involve more comprehensive qualitative work involving members of the general public as well as members of interested sections of society… We recommend that the Government initiates adequately funded public dialogue around the development of nanotechnologies. We recognise that a number of bodies could be appropriate in taking this dialogue forward (Royal Society, 2004, p. 87).

These institutions could be used a bridge between researchers working on nanotechnology and the risks of nanotechnology, and the public as well as policy-makers. The need for such a clearing-house seems to confirm what has been noted earlier. Krohn suggested that instead of leaving actors alone with infinite amounts of information, it would be better if there were "*an agency promising to be specialised in knowing how to read and use information*" (Krohn, 2001, p. 8140). This insight has to be seen as very much opposed to generalised statements, such as 'educate the public' (Nanologue, 2006). However, the point must be to provide information that is based on a person's ability to comprehend, be it members of the public or a policy-maker, in order to "*minimize the likelihood that the public develops polarized perceptions of nanotechnology based on rumour and supposition and hence avoid potential overreactions such as those that occurred with GMO*" (Currall, King, Lane, Madera, & Turner, 2006, p. 155). In this regard, and considering that there is not much public interest in nanotechnology at the moment, appropriate recommendations still need to be defined. This does not come as a surprise when considering that even the EU's nanotechnology strategy remains vague with regards to ‘involving the public’ and only stresses the needs for: “*an ongoing dialogue with the media and public opinion, based on dissemination of scientific knowledge, to provide the public with an assurance that the potential dangers for health or the environment are being monitored, and also to forestall misunderstandings concerning nanotechnological developments*” (Commission, 2004, p. 83).

To summarise, the majority of recommendations provided in current research on nanotechnology, the ELSA of nanotechnology, and on either integrating the public in a debate or on informing the public about nanotechnology remain vague at best. The most explicit ones available to date are the ones, from and about, the Royal Society. Many of the other recommendations highlighted above are, albeit good-willed, too broad, too normative, and not very hands-on, and thus, not specific. Bar the example of the Royal Society, the majority of recommendations do not take ‘know-who’, ‘know-what’, ‘know when’ or ‘know how’ into account. In other words, the majority of recommendations lack specificity with regards to who needs to do what, how and by when should it be done?

As for Nanologue and their study, an additional criticism of their recommended actions and recommendation is that Nanologue failed to make a distinction between recommendations for public research and the private sector, corporate research. Nanologue did not distinguish between who needs to do what. For instance, the majority of the 17[41] recommendations summarised in Table 14 are not applicable to the corporate world, as many of them are simply of no concern to corporate funding. In addition, Nanologue did not distinguish between what can be known by, for instance, members of the public, or, simply put laypersons. As mentioned before, Nanologue’s study has been one of the most comprehensive to date and the areas that have been criticised throughout this thesis are only symptomatic for what has been standard practice when studies and research that have been carried out provide recommendations.

[41] Nanologue’s recommendation extends beyond the ones mentioned here. For the purpose of this thesis, the 17 most relevant have been extracted and summarised in Table 14.

6.4 Applying the findings to theories of the policy process

Following the research findings of the aforementioned studies by Kahan *et al.* (2007, 2008), Nanologue (2005, 2006) and Currall *et al.* (2007), three things have become clear:

- there is not enough knowledge about nanotechnology,
- there is not much interest by the public
- there is not much known about the ELSA's of nanotechnology.

Although this does not seem to be a problem when approached from Ostrom's point of view, it somewhat feeds into Moe's general statement about the expertise problem, that is, the general lack of expertise when it comes to scientifically unknowns. This premise, however, is an issue when it comes to Sabatier's AC point of view. In advocacy coalitions, information plays a key role. The situation gets worse, when expertise is limited. As noted by Nanologue (2006), a number of nanotechnology experts felt uncomfortable answering questions about the ELSA of nanotechnology, as they saw nanotechnology itself as the area of expertise, but not the ELSA's. In a more practical example, once could argue that researchers such as Babu *et al*. (2006), Oberdörster *et al.* (2007) *and Guo et al.* (2008) are all experts in nanotechnology, and as such may either not be able or willing to acts as experts for nanotechnology risks. Furthermore, questions remains to what extent such a pure research scientist would fit with the use of information at the advocacy building stage, that is, to build coalitions of like-minded actors. The likelihood that existing advocacy coalition members are trying to extend their coalition by ELSA experts is much higher. This seems also supported by the Nanologue findings, which suggests that the interest of the pure scientist in regulatory affairs is somewhat limited. What is more, the participating researches in Nanologue's study actually demanded additional information on nanotechnology for non-experts, for instance, if these non-experts were involved in creating regulation (Nanologue, 2006).

The previously stated lack of general information on nanotechnology is also a problem. Although the approaches of Ostrom and Moe do not directly emphasise the use of information, when it comes to making policy choices, at least at some point, the use of information is required. Ostrom's approach of search and trial-and error learning in order to reduce uncertainty seems somewhat problematic in the light of a complex subject matter, such as nanotechnology. The most obvious reason is the generally acknowledged (Nanologue, 2006; Currall, King, Lane, Madera, & Turner, 2006) lack of available material for non-scientists. The material that is already available is mostly of a pure research nature; and if it is corporate research, then it is even less likely to be available. Even if participants in Ostrom's model were able to work with pure science publications and also able to extract relevant information for policy purposes, time would always be the issue. P. M. Haas (2004) already pointed out that the time necessary for developing credible knowledge is too long, and as such, time tends to interfere with the short-term needs of using knowledge in making policy. The same principle applies to Ostrom's approach.

Nonetheless, information plays a role here. It is used as a measure, for instance, when it comes to past performances. The decision to trust an actor is based on available information with regards to whether this particular actor has been trustworthy in the past. When considering the novelty of nanotechnology, two assumptions can be made: either the actors involved in nanotechnology policy-making are new, as the subject matter is new or the actors are the same, only the subject matter is new. In the first instance, information about the trustworthiness of actors would not exist. In the other example, information about the trustworthiness of actors would play a major role, but these 'known' actors would not have any particular knowledge about the subject matter, which may either be perceived externally as a problem or by the actors themselves, as they potentially would not want to jeopardise the trust gained and built-up over time. Both scenarios have a profound impact on the dynamics of the institutions. As actors assume that their goals can be best achieved through institutions, actors will attempt to maximise their efforts in order to do so. Thus, specific choices over institutional arrangements will differ not only in both of the above scenarios, but also between actors. The uncertainty that is currently inherent in nanotechnology could lead to a multitude of actors trying to advance their interests according to their own preferences; there is no guarantee that they would work together and could form a somewhat collective opinion of the issue at hand. In the case of nanotechnology, this, however, is exactly what is currently required.

Although information plays a key role in the AC framework, the lack of information also has an impact. This has to do with the fact that advocacy coalitions tend to use information during the coalition building stage. Here, the awareness about the lack of information, as documented by Nanologue, is in itself information, and, as such, could be used by a coalition to their advantage. For instance, any new and emerging technology, such as nanotechnology, needs time to reach a larger audience. If, in an advocacy collation stage, existing members have already some awareness of potential issues of nanotechnology, then exactly this information could be used as perception filter in order to strengthen the coalition's core belief well in advance before opposing views become known. Also, knowing that the provision of some knowledge to individuals without prior knowledge of nanotechnology tends to exacerbate existing opinions (Kahan *et al.*, 2007; Peter D. Hart Research Associates, 2008) can be used actively to the advantage of a coalition.

In Moe's structural choice framework, the lack of available information is less of a problem. Here, political uncertainty is a primary force between competing actors often resulting in political compromise at the expense of technical expertise. Thus, technical information, such as about the risks of nanotechnology, play a lesser role. However, as interest competition impacts outcomes with regards to the achieved compromises, the lack of available information could be used by one of the participating groups to their advantage. By withholding information, for instance, dominant groups could shape structural decision to their advantage. The question that remains is whether this would have long-lasting impact? Moe sees structural choice as a perpetual process that never ends; choices can be modified or reversed later: "*Battles lost today can be won tomorrow, and vice versa*" (Moe, 1995, p. 146). However, Moe make one additional and crucial point: in the context of political parties in government, structural decisions are taken at the start of the reign of a political party and "[m]*ost of the pushing and hauling in subsequent years is likely to produce only incremental change*" (Moe, 1995,

p. 146). Here, the lack of information, be it due to its unavailability or because it has been withheld does impact structural choices.

An associated aim of the knowledge framework was to use the different knowledge types in an attempt to identify which, if at all, could be used or explain the terms information, knowledge and expertise used by the aforementioned theorists. To reiterate, Ostrom uses the term information with regards to the information-processing capabilities of actors; either in model-building by assuming that actors can have complete information and infallible information processing capabilities, or by applying what Ostrom calls 'bounded rationality', which is assuming that actors have much weaker information processing capabilities. In both cases, nonetheless, Ostrom is not specific about what type of information this could be. However, she does specify what she considers what this information is to encompass: "*information available to a participant … about actions, outcomes, and their linkages…*" (Ostrom, Gardner, & Walker, 1994, p. 31). Unfortunately, this is very vague, when compared to the knowledge framework. From a decision-making perspective, this could include policy information and other descriptive and explicit knowledge used for policy making. It also could include technical expertise or acquired direct knowledge by any of the participating researchers at any of the stages in Ostrom's model. It also may not. Thus, it might be more useful to limit this assessment to the 'bounded rationality' stage, where actors, simply put, cannot process all available information, and therefore, where information may remain unused. "*Under bounded rationality, the information needed for many of the rigorous selection criteria is not assumed to be present*" (Ostrom, Gardner, & Walker, 1994, p. 35). In many cases, it is assumed that the amount of available information is larger than the information processing capacities. Thus, a rather large amount of available information will not be utilised and, as a result, actors are going to make mistakes. Here also, no further insight is provided about the type of information missed by participating actors. Again, this could include any or some of the types used in the knowledge framework, but it may also not. This is unfortunate, as by using specific information types within Ostrom's model, the outcomes could be fine-tuned and the results could potentially become more accurate. Furthermore, and although this cannot be said with any degree of certainty do to the lack of details, the opposite could become true. Due to lack of specificity of the type of information used on Ostrom's model, some result may potentially lose their validity, when specific information types are assumed. For instance, instead of using 'general information', that is, descriptive and explicit information about nanotechnology in Ostrom's model, one could use hands-on, personally acquired information. In such a case, the assumption that perfect information exists among all participating actors would be immediately wrong as soon as one of the participating actors were not a hands-on nanotechnology researcher. Even when using the bounded rationality, and even when assuming that not all available information is used, the approach would still struggle when there were obvious differences not only due to the amount of information that can be processed, but due to the lack of one or more actors' capabilities, or better said, knowledge.

For Moe, the emphasis is on expertise. As it has been established in the knowledge framework, expertise is always direct, and thus, acquired knowledge. Furthermore, expertise can also include descriptive, and therefore, indirect knowledge. However, descriptive knowledge does not include acquired knowledge and explicit knowledge does not include tacit knowledge. Therefore, Moe's use of expertise is an ideal candidate to analyse with the knowledge framework. Moe's point is that in order to exercise power in complex situations, for instance in the case of nanotechnology, the dominant groups simply lacks the knowledge and expertise.

Seen from a very simplistic perspective, one could argue that this is exactly the case as described by the Nanologue group. The lack of knowledge, and the dependency on expertise, which, in the case of nanotechnology is also lacking due to its novelty, leaves only one choice in decision-making situations: the reliance on external expertise. If one were to follow Moe's assumptions, this, however, would weaken any dominant group. In addition, it would also pose a legitimacy problem, if, for instance, a government were to follow Moe's example and create legislation only to the extent that it practically can do, based on available knowledge, while leaving technical aspects to external expertise providers. In this scenario, any dominant group following this example would not be able to explain the contents of the taken policy-choices, and their rationale to the public. However, in reality and based on current knowledge, the situation is actually much worse. This is due to the fact the dominant or challenging groups do not own or have access to nanotechnology expertise. As such, this possession of knowledge or access to it is still extremely rare, especially outside the corporate world. What is more, as established before, expertise in nanotechnology is not the same as expertise in health or environmental risks and impacts of nanotechnology. This type of expertise is even rarer. Under normal circumstances, Moe's model predicts that technical expertise normally suffers due to political compromise between dominant and challenging groups. In the case of a just emerging technology, such as nanotechnology, this does not hold true because of the lack of relevant expertise required in these choice-situations. In fact, when following the example as described here, then one could argue that the central dynamic of Moe's framework is not triggered until a sufficiently large enough body of knowledge on the subject matter in question has been established. For this in-between period, that is, the time between the emergence of a new highly complex, and expertise-dependent technology and the establishment of a large enough body of knowledge, Moe's structural choice framework has been cancelled out. When following this model further and when considering the current levels of corporate funding (see Chapter 4.3) and corporations' ability and speed to bring products to market (see Chapter 4.4), one could argue that the public interest would be left vulnerable during this 'in-between' phase, as those who steer public interest are forced to rely on the body of knowledge available to all. Corporations would be at an advantage, as they have access to the same body of knowledge available to all plus their own knowledge held in patents and accumulated by their own experts.

Sabatier uses the term information in a fashion that often represents technical information or quantitative data. For instance, by providing the example of air pollution, Sabatier's view of information is that of technical information used in policy change (Sabatier, 1988). As such, this type of information is policy information, when compared to the knowledge framework. It is policy information; because it is usable information in the sense P.M Haas (2004) defined policy information: it is usable by actors involved in making policy choices. But, it is more than just policy information. An important aspect of the AC framework is the use of information very early on in the process, for instance, when choosing new, but like-minded participants of a coalition. Here, this type of information has a strategic attribute, much more in an economic sense than that of policy knowledge. It is strategic in nature, as its intended use is of long-term vision. Such information comes very close to the type of information described in corporate or business contexts; it is mean to "*change the way the receiver perceives something, …*" (Davenport & Prusak, 2000, p. 3). This strategic information becomes even more important when viewed from Keohane and Nye's political perspective, where strategic information becomes even more important when the competitors do no possess it (Keohane & Nye, 1998). This is, however, not to say that this is the goal of information use in Sabatier's framework. Yet, such knowledge does provide an added advantage for advocacy coalitions.

In addition to policy and strategic knowledge, advocacy coalitions make use of one added type of knowledge. As the knowledge framework showed, both explicit and descriptive knowledge are the types of knowledge most likely understood by the public. Thus, the nature of advocacy coalition to use various means to support their views, engaging and convincing the public can only be done by providing information that is understood. To reiterate, this is also one of the basic principles that distinguishes information from pure data; only what is understood can be regarded as information. Here, the issue with nanotechnology is that much of the information that can be understood by the public needs to be created first, before it could be distributed. This, in turn, could also hinder or, at least, slow down the advancements of an advocacy coalition. Thus, the current lack of available and usable information can also pose a temporary problem to the AC framework. When coupling this with the aforementioned current dominance of corporate funding and investing, the question that needs to be asked is could an advocacy coalition be dominated by corporate players? In principle, the answer is yes. Competing advocacy coalition competing in political sub-systems is one of the defining functions of policy-change as seen by Sabatier. These policy-subsystems are not limited to areas of government; instead they include "*actors from a variety of public and private organizations who are actively concerned with a policy problem*" (Sabatier, 1988, p. 131). Sabatier goes even further and argues that it should "*include actors at various levels of government active in policy formulation and implementation, as well as journalists, researchers, and policy analysts*" (Sabatier, 1988, p. 131). Therefore, by definition, an advocacy coalition could include corporate representation, or even corporate bias. However, as competing views are often mediated by policy brokers, a complete corporate dominance seems unlikely. What needs to be kept in mind that the goal of an advocacy collation is policy change, which does not happen in a vacuum. Boundaries, such as cultural and social values and existing legal structures apply to all competing advocacy coalitions.

6.5 Summary

The main finding of this chapter can be summarised as follows: First, the previously established fact that the public does not know much about nanotechnology becomes even more an issue when taking the results from the applications of the knowledge framework into account. By distinguishing between different types of knowledge, in this case, knowledge of and/or about nanotechnology, the knowledge that should be made available to the public is descriptive and therefore explicit knowledge or information. When considering the complexities of nanotechnology, as it has been shown by the example of studies carried out by Babu *et al.* (2008) and Oberdörster *et al.* (2007), it becomes apparent that this is an issue. It is an issue because the public lacks the capacity to comprehend these, as these studies are mere matters-of-acquaintance (James, 2002) and are therefore realities that can be known only directly. A number of recommendations made by researchers (Nanologue, 2006; Currall *et al.*, 2006; Maynard, 2006, Scheufele *et al.,* 2007, Kahan *et al.* 2007) and other organisations (ESRC, 2007; Royal Society, 2004) involved in nanotechnology have acknowledged the need for public engagement, be it due to the acknowledged complexities or due to lessons learned from the past (i.e. GMO). However, without looking at the different types of knowledge involved and thus without defining the required knowledge needed to reach a target audience, in this case the public, nearly all recommendations fail short on how exactly a positive dialogue with the public can be initiated.

The second main issue identified is that of education and (political) advisory. Although a number of studies highlighted the areas directly (Nanologue, 2006) or indirectly (Royal Society, 2004), so far, no-one has been specific as to how to implement this. When it comes to education of the media, a popular example, studies have shown that the media currently has no appetite for nanotechnology stories (Petersen, 2006). Even tabloids, who after all reach the majority of readers in the UK or Germany, for example, shun the topic. The sames goes for quality newspapers; nanotechnology is not a popular topic. What is worse, even if it is reported upon, the majority of articles are not authored by educated science and technology correspondents (Petersen, 2006). A recommendation that has been proposed by the Nanologue Group suggests that public administrations and politicians 'should stay informed' about nanotechnology developments and that the public 'should be trained in popular sciences' (Nanologue, 2006). Both, however, are problematic when viewed through the knowledge framework. By looking at source and at the target audience, it becomes obvious that a knowledge transformation needs to happen. To overcome this obstacle, two different options were discussed.

Option 1 focussed on letting nanotechnology researchers being the informers, be it to the public or to policy-makers, and Option 2 introduced knowledge elicitors aimed at converting directly acquired knowledge into explicit and thus descriptive information. Some researchers (Nanologue, 2006) suggested that funding should be used to mandate a dialogue with the public; others suggested that that only in the spheres of public research funding should be used to encourage public engagement (Currall, King, Lane, Madera, & Turner, 2006). This limitation to the sphere of public research stems from the insight that as of 2007, the majority of nanotechnology related research is now being funded by corporations (see Chapter 4.3). Another limitation that has been identified for Option 1 is that not all (public) researchers have the ability to engage the public. Experts excel by both a great amount of knowledge and advantageous knowledge organisation in order to make functional and efficient use of their knowledge (Gruber, 2001). This, however, does not mean that experts are automatically experts in knowledge organisation or that an experts' personal approach to knowledge organisation is of such generic nature that it is open and accessible to everyone. According to research on expertise, it is being suggested that experts, no matter their domain, are often not good communicators on their own subjects. This is due to the fact that they often use their own language/technical jargon, have their own styles and are often not explicitly aware of the amount of knowledge they have (Firlej & Hellens, 1991).

Thus, using funding as an instrument to mandate pubic engagement might not only being seen as discriminatory by some, but also might 'drive' some public researchers towards the industry, where such a mandate could not be enforced. In this regard, Option 2 offers to be a better alternative, as it could make use of elicitors who have the skill to drive out information from experts, no matter whether they are aware of their own domain-specific knowledge or not. However, this option has some downsides as well: costs, the limited number of people available with knowledge elicitation skills, and similarly to Option 1, it would have to be based on voluntary agreements and therefore focus mainly on publicly funded research. Although neither Option 1 nor 2 are perfect solutions to minimise the current gap in public knowledge about nanotechnology, nor are they a perfect solution to the identified issues with regards to recommendations to involve the public. What they are, however, are a step in the right direction by taking care of the knowledge issue with regards to the target audiences, in this case, the public and policy-makers.

A number of authors (ESRC, 2007; Currall *et al.*, 2006; Nanologue, 2006) have stressed that lessons need to be learned from the GMO case when it comes to openness and transparency. Yet, transparency in itself will not change the public debate on its own, nor will it provide ultimate answers for policy-makers. If the public cannot be involved because they are either not aware of what is happening or because they cannot get access to the information an intended dialogue itself will not achieve much. Moreover, if the public cannot participate because of the lack of skills and knowledge then this puts new, and probably unexpected, challenges to all actors involved that have an interest in setting up a public dialogue.

The application of the knowledge framework to the three selected theories of the policy process also yielded a number of interesting results. Firstly, Sabatier's advocacy coalition framework makes most use of different the types of knowledge, depending on the goals of such a coalition. Information is used as policy information, when appropriate. It is also used as strategic information in order to shape the composition of a coalition. And finally, it is used as a form of indirect knowledge when an advocacy coalition aims to convince wider audiences, such as the public, of their intentions. Although the use of the knowledge framework allowed for the identification of these different types on knowledge and information, it is not to say that Sabatier had this in mind when developing his approach.

An unexpected consequence of the use of the knowledge framework was shown when applying it to Moe's structural choice approach. Instead of using the term information, Moe described expertise dependency that exist as a result of lacking knowledge by dominant groups. However, in the case of nanotechnology, or any other just emerging knowledge-intensive and complex technology, Moe's approach cannot account for a scenario where the expertise requirements cannot be fulfilled due to a lack of such expertise, or the lacking access to it. Here, it has been suggested that during this 'in-between period', that is the time between the emergence of such technology and the growths of a sufficiently large enough body of knowledge, Moe's approach cannot be used.

The analysis of Ostrom's institutional rational choice approach yielded the least useful results due to the unspecific nature in which Ostrom uses the term information. Without making further assumptions and thus adding to the uncertainty about Ostrom's use of the term information, what can be said for sure is that if Ostrom had specified different knowledge types, a number of outcomes IRC scenarios could potentially be fine-tuned in order to potentially achieve more accurate results.

Finally, the lack of specificity when using terms information or knowledge in policy context has been highlighted throughout this chapter. The same can be said for policy recommendations or recommendations to the public. Information always requires understanding by the receiver. Using the wrong type of information simply results in information not being received. This can have dire consequences, for instance, when the public either does not have information at all or when the public's needs have been addressed by using the wrong type of information. As studies by Nanologue and others have shown, currently the public has neither sufficient information nor the desire to learn about nanotechnology. The latter makes the overall situation worse, and more complicated for policy making.

7. Conclusions

The thesis set out to investigate whether increasing complexity and knowledge-intensity will challenge policy-making and also hinder the public's ability to participate in the public debate? This was based on the proposition that due to the increasing knowledge-intensity and complexity of new and emerging technologies, a distinction between various types of information and knowledge is beneficial, if not required/necessary, in order to benefit both the public discourse and policy-making. Furthermore, it was proposed that by distinguishing between various types of information and knowledge, theories of the policy process can be assessed for their applicability to complex, knowledge-intensive and expertise dependent subject matters, such as nanotechnology. The overall assumption was that the public has no first-hand and thus direct knowledge of this, and that even second-hand knowledge is only partially understood. The latter also applies to the majority of policy-makers, who are not experts in the fields of nanotechnology.

After briefly summarising the main findings of nanotechnology, this conclusion will summarise the answers to the above questions. First, an assessment of the application of the knowledge framework to the policy recommendations and recommended actions by Nanologue and other researchers will be provided. This is followed by the assessment of the application of the knowledge framework to the three theories of the policy process. Finally, an outlook will be provided for the further study of policy-making and nanotechnology.

Nanotechnology

Investigating one knowledge-intensive area in detail was one of the additional aims of the thesis. Nanotechnology was chosen as an example of a technology that potentially will lead to increasing complexity and knowledge intensity with long-term consequences. An increase in worldwide funding of previously unseen proportions highlights nanotechnology's rising importance effectively. Despite the complexities of nanotechnologies, a number of products that are either based on nanotechnology or that contain nanoparticles are already available; approximately a quarter of them contained one particular product: nanosilver. This is problematic, as nanosilver has potential negative impacts on aquatic life, but also in food-production, as recently confirmed. Moreover, there is a general lack of existing knowledge in areas such as detection and characterisation of nanoparticles, their environmental fate and transport, and their toxicology and in particular their ecotoxicology. This knowledge, however, is not only important in order to better determine health and environment-related impacts, but it is absolutely vital when it comes to formulating appropriate policy or when it comes to encourage public debate. An additional current issue is that the public does not know much about nanotechnology, nor does it seem to be interested in it.

Another objective of this thesis was to establish a framework that focuses on different knowledge types that can be used to make distinctions vital in practical contexts. This knowledge framework is a matrix for comparing different types of knowledge and information. In particular, the framework covered the five different types of knowledge: knowledge by acquaintance and tacit knowledge as forms of direct knowledge, and knowledge by description and explicit knowledge as forms of indirect knowledge as well as policy knowledge. The aim was to apply the different knowledge types against technical data about nanotechnology, and nanosilver in particular, and against the results of intensive qualitative surveys undertaken by Nanologue and other studies: By identifying 'knowable content' by groups of 'knowers', the applicability and usefulness of policy recommendations and recommended actions were assessed.

The Nanologue group made a number of recommendations. A selection of them has been assessed for their dependency on the transformation of tacit knowledge into explicit knowledge. Six of the recommendations were dependent on the occurrence of this knowledge transformation. In addition, four of the listed recommendations were found to be dependent on research being publicly funded and another four other were dependent on the good-will of the media. When comparing Nanologue's recommendations with that of other research, it put Nanologue's findings in perspective, and it was shown that they were fairly representative of what is common practice when providing recommendations. This common practice is characterised by its focus on a rather wide spectrum of recommendations with regards to target audience and suggested actions while at the same time, lacking specificity. The majority of recommendations remain vague at best, as they remain good-willed, yet far too broad, too normative, and not very specific. Out of all recommendations reviewed for this thesis, only the Royal Society was specific; the majority of recommendations do not take 'know-who', 'know-what', 'know when' or 'know how' into account, and, as shown when compared to the knowledge framework, do not distinguish between different types of knowledge. By employing a best case scenario, the importance of doing so has been illustrated effectively, as in reality, overly positive scenarios as such do not exist; at least not with regards to nanotechnology or nanosilver.

A number of recommended actions of the Nanologue group suggest training the public in popular science and science literacy and explaining the benefits of nanotechnology to society. Although this suggestion is good-willed, and factually not incorrect, it only describes ways of reaching the public, but not the means to ensure that the public accepts the offered training. Unless the public sees a personalised benefit in gaining knowledge, informing the public may not yield the expected outcomes; such a personalised payoff seems unlikely given the absence of any targeted instruments for inducing this. The problem with nanotechnology is that the public has no interest in it. As this has been established by Nanologue and by other studies, it came as a surprise to see Nanologue suggesting the 'correct use of mass media'. In this regard, Nanologue highlighted that correct framing of issues is vital and suggested to focus on the benefits of nanotechnology. However, the question that needs to be asked here is whether this might not achieve the opposite? If the dialogue with the public should be transparent and open, as suggested by the participants of Nanologue's study, would intentionally positive framing not bear the risk of coming across as being dishonest, if found out? Nanologue argues that the reason is to avoid a public information overload. Again, the problem is the lack of specificity with regard to 'what can be known by whom'. Without making an assessment about what information can be provided to whom, and what the likely uptake is, these recommendation and recommended actions fail to acknowledge the complexity of nanotechnology. This is somewhat surprising, as Nanologue learned from the attending researchers, that many that were experts in the field of nanotechnology were not comfortable with the ELSAs of nanotechnology and indicated that they lacked an overview of the subject matter that is ELSA (Nanologue, 2006). It was this particular statement that made it clear that a distinction between nanotechnology experts and experts of ELSA of nanotechnology needs to be made; an expert in nanotechnology is not automatically also an expert in the impacts of nanotechnology, for instance, environmental or human health impacts. If a researcher is an expert in working with nanoscale silver particles, it does not make him/her an expert in the impacts of nanosilver exposure.

The difficulties of accessing and harnessing expertise have been highlighted throughout this thesis. One of the additional objectives of this thesis was to identify tools that could help overcome potential stumbling blocks for policy-makers and the public. Two of these tools have been identified as alternative means of accessing expertise. The first option refers to using experts directly as the group that informs the public and advises policy-making. Here, two problems have been identified:

1. It requires the experts having the relevant communication skills, which is not always a given.
2. A number of experts work solely on individual components and could therefore only report on parts of what potentially be bigger issues.

Thus, this option has its limitations. However, in instances where these two issues do not occur, it must be regarded as the preferred option. To put it in the context of the knowledge framework, this means that if the holder of acquired expertise can utilise personal skills that enable him/her to transfer this knowledge without a loss of information into publicly understandable, descriptive knowledge, then the resulting descriptive knowledge holds the potential to be (nearly) epistemically equal to that of acquired knowledge.

The second option suggests utilising knowledge elicitation. The advantage is that knowledge elicitation does not rely on the original expert to be the informer, thus circumventing the two issues highlighted above. Retrieving knowledge from an expert is done by knowledge elicitors whose task is to document an expert’s skill. The advantage of using knowledge elicitation is that acquired first-hand knowledge can be obtained that otherwise would not be available. Furthermore, additional information may be revealed of which the domain knowledge holder may have not been aware. The main obstacles are cost, availability of knowledge elicitors and access. The latter becomes an issue when research is funded by corporations, as the majority of nanotechnology research already is today. Another advantage is that knowledge elicitation can be used to target specific areas, thus allowing governments, institutions and organisations to obtain specific knowledge and information as per their needs. Again, the preferred option must be option 1, but this is limited to the instances described above. Hence, option 2 should be utilised as well for as long as cost, access and availability of knowledge elicitors are not an issue.

When trying to apply the problems that come with complex, knowledge-intensive and expertise depended new technologies to society, be it to evaluate risks vs. benefits or to carry out a prognosis on the long lasting impacts, it becomes clear that technology itself is not the problem. The problem is one of culture, cultural acceptance and change. As has been shown in this thesis, nanotechnology is complex, difficult to understand by a layperson and yet it is not nanotechnology itself that poses difficulties. Recent studies into public perception of nanotechnology show that it is wrong to assume that 'all that needs to be done' is to inform the public with scientifically sound information. This is not only due to ordinary citizens lacking both time and expertise to assess information properly, but also because people tend to evaluate information based on their own cultural disposition and preference, that is, existing values often play a greater role than available scientific knowledge. Public perception of nanotechnology is imperative for shaping the future of its development. Past experiences have shown that negative public perception can shape the direction and pace of scientific activity. Nuclear power, GMO, embryonic stem-cell research and biotechnology are some of the best known examples.

Theories of the policy process

Another core objective of the thesis was to assess selected criteria of a number of theories of the policy process with regards to the usefulness of identifying different types of knowledge and information. The use of the knowledge framework, for instance, helped to establish that knowledge by description and explicit knowledge have one major downside; laypersons still require the help of expert knowledge holders to understand things that go beyond mere factual knowledge or headline information. In a policy context, the main aim of information is actually to reduce uncertainty and to increase clarity and consistency of decision-making as well as to improve the quality of public debate. This pertains to the public and to policy-makers alike. From an expert-knowledge point of view, there are doubts as to whether policy-makers are able to properly manage and respond to these challenges. It has been suggested that the use of scientific knowledge in decision-making and policy-making is still insufficient. The reliance on experts and, therefore, on their authority is problematic at best. Due to the nature of expert knowledge, a clear distinction must be made between producing knowledge, offering an expert opinion and decision-making. This has been confirmed by the application of the knowledge framework; data, information and knowledge available to policy-makers differ from that available to experts.

It has been argued throughout the thesis that the correct use of terms, such as data, information, knowledge and expertise is increasingly important for policy-making and for the policy sciences. With regards to policy making and the importance of information and knowledge, this view can also be found in the literature. A similar view, however, cannot be found when it comes to the theories of the policy process. Thus, the knowledge framework has also been used to assess three theories of the policy process in order to investigate the usage of information, knowledge and expertise. To reiterate, Ostrom uses the term information to describe information-processing capacities of actors, Moe uses knowledge and expertise dependency as key component, while for Sabatier information also plays a key role in in advocacy coalitions.

Ostrom (1991) uses the term information in her IRC approach in a rather unspecific and generic fashion. Information is used with regards to the information processing capacities of actors. The application of the different knowledge types of the knowledge framework, from which different information types can be derived, showed the least useful results. This was due the lacking specificity given to information in Ostrom's approach, which, in turn, makes a proper analysis of potential impacts of specifying different knowledge types very difficult, without adding further assumptions. This should be avoided, as this could lead to adding even more uncertainty about Ostrom's use of the term information. Therefore, what can be said is that if Ostrom had specified different types of information, a number of outcomes of the ICR scenarios could potentially be fine-tuned in order to achieve more accurate results.

Moe (1995) did not use the term 'information'; instead he used the term 'expertise' and argued that expertise dependency is a result of the lack of knowledge of dominant groups. When using nanotechnology as an example, the application of the knowledge framework showed that Moe's approach failed to account for a scenario where required expertise cannot be provided, simply due to its unavailability. However, it has also been established that this period is limited to the time when a new complex and knowledge intensive technology, such as nanotechnology, emerges and the time required until a sufficiently large enough body of knowledge has been established. During this 'in-between' period, however, the central dynamic of Moe's approach is not being triggered. As a result, Moe's assumption that technical expertise is being sacrificed for the sake of political compromise, due to constant use of arguments and counter arguments of opposing groups may not hold true, as, simply put, there is not enough data, information and knowledge available that could support opposing arguments.

When applying the knowledge framework to Sabatier's advocacy coalition framework, it showed that information has various uses. It is used as policy information, it is used strategically, for instance, when it comes to shaping the composition of an advocacy coalition and it is used as a form of indirect knowledge, when advocacy coalitions aim to reach wider audiences, such as the public. The latter could also be described as an authoritative form of knowledge. Most commonly, however, information used in Sabatier's framework is policy information, that is, technical information or quantitative data used by actors involved in policy change. Policy information has to be adequate for its purpose; it has to be useful information. A lack of this information, as in the case of nanotechnology impacts Sabatier's advocacy coalition framework more than any other of the aforementioned theories. Although under certain circumstances it could also be useful (for instance, when information is generally scarce but some members of a coalition have some awareness), they could potentially use it to influence the composition of a coalition. In most cases, however, it is disadvantageous due to the fact that information impacts a coalition's core belief, and thus, determines the stance on a particular subject matter. One the one hand, the formation of this core belief could be delayed and give the opposing coalition sufficient time to form their counter-belief. On the other hand, if a general lack of information and knowledge is widely accepted, opposing views will take even longer to form, thus potentially delaying any action.

As this thesis has shown, much can be learned by acknowledging the differences that exist between the varying types of information and knowledge. The research has been approached as prototypical case study, that is, the assumption was made that findings from this research will play a greater role in the future, as the number of increasingly complex and expertise dependent technologies will only rise. Thus, one of the main findings of this research is that terms such as data, information, knowledge and expertise should only be used in a context-specific way, and most importantly, should never be used as a substitute for one another. This is the more important as the rising complexity of technology will also lead to a rise in complexity of policy-making. Making deliberate distinctions between various knowledge types can help to distinguish how information can flow from the expertise holder to the non-expert. It also helps to distinguish different types of knowledge holders, thus opening up options to better address information deficits. Based on what has been established in this thesis, further study should concentrate on investigating the impacts of knowledge on policy-making and *vice versa*.

Using Sabatier's framework to study knowledge in a policy context will be more fruitful than the study of knowledge using either Ostrom's or Moe's approaches. In both Ostrom's and Moe's cases, this is due to the already assumed limited information processing capability of actors and the expertise dependency. Sabatier's framework, however, offers more to the study of knowledge. One option would be to particularly assess the role core beliefs play on acquired knowledge. For instance, if there were already an existing belief on the environmental, social and legal aspects of nanotechnology, how, if at all, would that impact the acquisition of knowledge in that area? Similarly, and perhaps easier to accomplish, one could assess the impact of an existing belief on the availability of explicit knowledge. Would an existing core belief impact the amount of information available, and would competing core beliefs lead to an acceleration of the provision of explicit knowledge?

However, Moe's approach could also be further studied by applying different types of knowledge to different actors, such as the bureaucracy or political appointees, or to specific parts of government, such as the legislature or judiciary. Here, one could compare acquired expertise of professionals who function as independent experts to the descriptive knowledge of careerists who must concern themselves with political uncertainty. This could be studied under the assumption that both groups are constantly concerned with the pressures of reputational information, that is, how opposing interest groups and actors see them and how this impacts the utilisation of their respective knowledge types. Furthermore, by carrying out a comparative analysis, one could attempt to identify which of these is potentially more useful to either break the stalemate of political compromise or which of the two has the potential to ensure that technical information is not being sacrificed for the sake of short-term political victory.

Outlook

Further studies need to be carried out with regards to the impacts of nanotechnology. Although lessons can be learned from other areas, such as the climate change or GMO, the complexity of nanotechnology itself suggest that this may not suffice. If current trends of the number of already available and expected nanotechnology-related products are accurate, than the number and the variety of different types of products will go beyond what GMO production has delivered to date. Considering that the current focus, especially the corporate focus, is on mainly new nanotechnology based products, then both the simultaneous development of new nanoparticle detection technologies and health and environmental impact analyses of new nanoparticles are required. The main challenge here is to create incentives for corporations to combine product based R&D with research on detection technologies and the impact of nanoparticles on health and the environment. In turn, a number of current findings on nanotechnology should be applied to other highly topical issues, such as Climate Change or GMO. In particular, the findings with regards to the general of lack of public interest and about the influence of available information on the perceptions of technology risk have the potential to provide useful insights for policy-makers.

Then, the transfer of expertise requires both further study and further specialisations. In particular, studies will be required that detail the free access and transfer of expertise held by corporations, as it is assumed that this will differ from the accessibility and transferability of expertise held by public organisations. This should include further studies of instruments that would compel corporation to cooperate with such expertise transfer. Also, in addition to the two options already discussed in this thesis, new methods and tools that can be employed in expertise transfer require further study. This could be combined, for instance, with the continued study of knowledge distinctions, as introduced in this thesis. In particular, the study of knowledge by acquisition vs. knowledge by description yielded useful results and merits further research. Yet, this has not been studied much further since Russell. A promising candidate for further study is Sabatier's AC framework. Both the success and the dynamics of opposing coalitions could be studied by applying this concept against coalition members in order to measure and identify success criteria of advocacy coalitions.

Furthermore, policy studies would benefit from the existence of a classification of areas of technology by their inherent complexity. This is the more important as nanotechnology is only a forerunner; it is only one example of new sets/types of technologies of growing significance. Other emerging technologies are genetic and biomedical engineering and Synthetic Biology. Such a classification would benefit both corporate and governmental actors during the policy process. In particular, areas such as policy alternatives, conflict resolution and the evaluation of impacts would benefit from such as clarification. Especially the latter is of importance, as policy-makers need to fully understand what the consequences of their policy-choice are. In order to get that insight, the expertise dependency problem needs to be solved. Therefore, already existing technologies and highly complex issues, such as GMO or Climate Change, could also benefit from such classification. Considering the already dominant corporate funding of, and subsequent advances in nanotechnology, the relations between the state and corporations in terms of steering policy developments with regards to the new complex and knowledge-intensive technology also requires further attention.

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