Research councils facing new science and technology

The case of nanotechnology in Finland, the Netherlands, Norway and Switzerland

Frank van der Most

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RESEARCH COUNCILS FACING NEW SCIENCE AND TECHNOLOGY
THE CASE OF NANOTECHNOLOGY IN FINLAND, THE NETHERLANDS, NORWAY AND SWITZERLAND

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Dit proefschrift is goedgekeurd door de promotor prof.dr. A. Rip en de assistent promotor dr. B.J.R. van der Meulen.

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Preface

For me, the most rewarding experience in research has been discussing the issues of the day with colleagues – whether finding interviewees; writing a research proposal; discussing one's theoretical heroes, conceptual frames, or research findings; or even deliberating an idea that was raised during a coffee break. During the past five years, I have been fortunate to have worked with colleagues that are willing to engage in such discussions. I would like to thank them for exchanging thoughts and ideas about their and my own research. In addition, I would like to thank...

... Barend van der Meulen, for introducing me to the study of research funding organizations, for initiating the project that led to this thesis, and continue supervising me during a period where he was in the process of changing jobs. Barend welcomed me every time I wanted to discuss an idea with him and never let me leave empty-handed.

... Arie Rip, for accepting me as a PhD student, for introducing me to resource dependence theory, and for providing me with the right and evolving mix of academic enablers and constraints. I wish I had more time to take up one or two challenges that Arie offered me.

... all the interviewees, for their time and willingness to provide me with their experiences and insights. Besides those listed in Section 10.1, I would like to thank R. van Duinen, M. Gulbrandsen, H.J. Güntherodt, A. Klitkou, H.A. Klok, S. Kuhlmann, P. Kutinlahti and S. van Tongeren.

The PhD project is the last in row of project that I worked on during an almost 10 year stay with the department of Science, Technology and Policy Studies (STəPS) and its predecessors at the University of Twente. For the group, this was a period of constant change and occasional turbulence. However, the group never ceased to be pleasant, stimulating and open. *Geliefde collega's* – I will miss you.

A big thank you goes to my fellow PhD students, post-doc and project researchers, including those from the Philosophy department, for sharing and suffering the fun and setbacks of academic life in general and PhD research in particular. I am happy to say that it was fun for the most part. I mention setbacks because I occasionally complained, although I realize how little I had to complain about.

To Louis Neven and Haico te Kulve - having shared an office space with you for almost 4 years, it will be a pleasure and an honor to have you on board as *paranimfen* at the thesis defense. Thank you for taking that role.

To the members of the reading club – I enjoyed discussing the writings of scholars in the field of science, technology and society studies. Attendance levels have varied, so to say, but only two are required for a good discussion.

Through its educational program and annual meetings, the Netherlands Graduate School of Science, Technology and Modern Culture (WTMC) helped to broaden my horizons, both in terms of the content of my research and via networks. I cherish the days and weeks spent at Soeterbeeck in the company of fellow PhD students and wish to thank the coordinators Els Rommes and Sally Wyatt for their enthusiasm.

My research project was part of the Technology Assessment flagship of the Dutch NanoNed program, which allowed me to reflect on the societal aspects of nanotechnology. It was a rewarding experience.

Many thanks to Frank van Boekel, Roel Bossink and their colleague system operators, who have kept computer systems running in spite of the structural underrating of these systems and the efforts needed to use and maintain them. I am equally thankful to the volunteers who developed the OpenOffice and NeoOffice software packages, which I used to write this thesis.

Towards the end of my contract at STəPS, I spent four months at the Research Policy Institute (RPI) at Lund University. Mats Benner and his colleagues gave me a warm welcome and provided a stimulating environment to ponder my case material. I consider myself fortunate to have been able to return to Lund as soon as I did. As I write this preface, I am already enjoying cooperating with them and my new colleagues at the Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE). I look forward to the coming years.

Despite the fact that these are the first pages of this thesis, they are among the last that were added. To arrive at this point I have sacrificed time and resources, and during the last year or two, I neglected my friends and dearest increasingly more. Fortunately, they have not neglected me. To them, and especially to Anne, Bob and Mirjam: thank you so much for being there with me, all the time.

Frank van der Most

October 14th, 2009

1 Introduction

Research councils are plagued by the fact that science develops over time. The agility necessary to address new developments does not come easy to an institution like a research council. New questions, topics and fields, big and small, emerge and have challenging implications for all actors involved, including research councils. At least three pressing challenges exist.

The first concerns disciplinary boundaries. When research councils are launched or reorganized, the then existing boundaries can be taken up in their organizational structures. Later, new research topics and fields emerge and many can be located within the initial boundaries of the research councils. However, in the course of half a century that has passed since the first research councils were established, major new areas of research were developed which crossed disciplinary boundaries. Materials research emerged in the 1950s and 1960s, biotechnology in the 1970s, computer science and information technology in the 1980s, and nanotechnology in the 1990s[1]. Such interdisciplinary fields were difficult to position within disciplinary structures of the existing research councils. It is worthwhile to investigate how they solved this problem because the solution may affect not only the research council, but also the field as it develops.

The second challenge is that it is difficult to know beforehand how a new field will develop. How should it be defined or outlined, in which directions will it develop and how influential will it become? During some time, such questions cannot be answered unambiguously and this creates problems, or at least difficult choices for a research council with regards to how to support it.

Thirdly, new questions, topics and fields require adaptations of research infrastructure. Different instruments and facilities are needed, different organization of research, and different knowledge and competences are required from researchers. In part, these requirements pose challenges to research councils, and here too, the councils' solutions may influence the field's national development.

The three challenges lead to the question which is the central theme of this thesis:

> How do research funding organizations respond to emerging fields of research and what is the effect of the response on both the new field and the funding organization itself?

[1] The periods indicate when a particular field developed into a major category in research institutions. In each case, earlier developments can be identified.

The relevance of this question also relates to the trend where governments ask for more visible signs that basic research has social benefit and want to give priority to areas of research and outcomes. Targeted research funding directly financed by ministries or through research councils was introduced in the 1970s. New types of councils for applied research and technology development were established in the 1980s. Issues concerning intellectual property rights were put on the agenda of public research organizations. As of the late 1980s, governments, at least in some countries such as the Netherlands and Norway, reorganized councils to address societal issues in their funding activities.

Organizations for funding of applied research and technology development are not called councils but do finance research and deal with the same challenges of developing research. To capture the breadth of funding agencies, hereafter the label research funding organization or its abbreviation, RFO, is used.

For research funding organizations, the trend meant a shift in orientation. From their inception, they found themselves between two spheres, viz. government and research, each with its own reward dynamics. Initially, they were dominated by researchers. For decades, the RFOs used open project funding, a system in which researchers apply for financial support of individual research projects. Their applications were reviewed by their peers and financed until the RFO's budget ran out.

New emerging fields posed no challenge to such a responsive system. They would result in different project applications and different review behavior but both were left to the researchers. Researchers applying for interdisciplinary projects might find an RFO which is dedicated to a particular discipline receptive to their applications because of the overlap between the discipline and the project. Or they might find that such an RFO would reject them on the grounds that the project did not fit the respective discipline. The latter would be a problem for the applicants and the new field, but not necessarily for the councils. RFOs are still using this instrument, accommodating bottom-up developments in research. However, budget shares for open project funding have decreased in favor of targeted funding.

When pressure from governments increased, targeted funding was introduced. Targeted funding aims for the stimulation of particular topics or areas in research or society through funding programs. These can have different shapes and sizes in terms of budget reservations, organizational structure, funding instruments used within the program, and application and review procedures.

The funding programs turned out not only to be a solution but also to shift problems and invoke new problems. By the early 1990s, the external demand for societally oriented funding had shifted and transformed into an internal problem for many RFOs. Compared to open project funding, program funding requires identification of topics for prioritization, and then requires the design of a program.

To address the question introduced above, it is studied for the case of the field of nanotechnology. This is an interdisciplinary field which merges a wider range of existing disciplines than other fields before. It perhaps also exceeds earlier fields in terms of potential applications and societal sectors that may benefit. Although it is not that new anymore, the field is still under construction. It may well be becoming a major field of research. Further, nanotechnology experiments require high precision instruments that operate in ultra high vacuum or rooms free from dust and vibration, thus putting high demands on budgets. On all counts, it is a field that poses the challenges to the RFOs that were listed above.

Nanotechnology is not the only field that shows such characteristics. Biotechnology, materials research, and information and communication technologies are similar. However, nanotechnology is the most recent one and it plays out in a different historical context. The field developed when identifying new fields for program funding had become a salient issue for RFOs.

I will discuss research funding organizations and the field of nanotechnology in more detail, and then develop my research question.

1.1 Research funding organizations

Research funding organizations as investigated in this thesis are publicly financed organizations that financially support research performed at public or private organizations[2]. This condensed description requires further elaboration.

RFOs are publicly financed, which means that they receive most of their budget from one or more ministries. RFOs thus have always been dependent on them. They were launched by ministries of science and education as part of research policies, but also by ministries of health, agriculture, defense[3] and economic affairs within their respective policies. When launched, RFOs' administrators needed input from researchers to legitimately distribute funds and it took efforts and adaptation on their part to acquire such input and involvement of researchers. After they succeeded and researchers participated

[2] Besides public RFOs, a category of privately financed organizations for research support, private RFOs, exists as well. Their budget providers include patient organizations or charities established by companies or wealthy individuals.

[3] RFOs under ministries of defense are not taken into account in this thesis because their activities are not publicly accessible.

in advisory committees and peer review processes[4], researchers came to see RFOs as normal part of research. RFOs changed in the course of that process, but the development also changed reward and reputation systems in research. Acquiring a grant became an indicator of scientific quality and credibility. (Rip, 1985, p. 84, 86; 1994, p. 7 - 8)

RFOs thus also became more than mere distribution machines. They have developed a convening aspects as well. Many also coordinate research and support contact between researchers. They may organize conferences and seminars and may have elaborate structures of specialists committees or working groups which on a regular basis discuss research developments[5], similar to how the Academies of Science organized contacts between researchers. This convening aspect is another example of how RFOs became adopted as part of research practices.

RFOs show diversity in focus on different types of research and a division can be made into three categories, although some RFOs turn out to be hybrids. RFOs for basic research have been introduced and described at the start of this chapter. The RFOs for applied research and technology development have been mentioned but not described. In contrast to RFOs for basic research, which are usually labeled research councils or academies, technology RFOs are often labeled 'agency'. This indicates that they are administrative bodies under direct control of their financing ministries, usually ministries for economic affairs. This means that contrary to RFOs for basic research, the ministries can commission the technology RFOs to launch a particular program. They also have greater distance to researchers, which means that researchers are less or not involved in practices of program development and not involved in proposal reviews.

In the course of the last decade or so, a third type of RFOs has come into being: the innovation agencies. In some countries, such as Switzerland and Finland, technology RFOs have been relabeled innovation agency whereas their tasks remained unchanged. In other countries, such as Norway and Sweden, innovation agencies were established[6] with the aim to support innovation, which is taken to be more broad than funding of applied research or technology development, and may involve support and stimulation of entrepreneurial activities, large companies, small and medium sized enterprises, regional development, and stimulation of particular sectors or types of companies (Innovasjon Norge; VINNOVA, 2008).

[4] Rip (1994, p. 7) points out that involvement of members of the research community and peer review of proposals were in part a product of administrators seeking scientific legitimation of funding decisions on basic research.

[5] Such communicative aspects and other structural aspects of research practice, such as education, travel and exchange of researchers, have become targets of financial support.

[6] In Sweden, VINNOVA was the result of a reorganization of the former National Agency for Industrial and Technical Development (NUTEK) (Granat Thorslund, Lennart et al., 2006, p. 18)

RFOs' business is financial support for research. To do so, they have developed different types of instruments and within each type many different shapes and forms can be found. Besides open project funding and program funding, RFOs instead or in addition support research through institute funding, either on a permanent or temporary basis.

Permanent support of research institutes, big or small, has been, and in some countries such as Germany and Austria still is, a major form of research funding via RFOs[7]. Because of the often permanent character of such support, it allows for relatively little room for maneuver to respond to new fields of research.

Some RFOs and funding instruments have been developed, for example in Sweden and Switzerland, which adopted a less permanent approach. They finance institutes for a number of years, ranging from 5 to 12, and leave it to other actors to continue funding afterwards.

1.2 Nanotechnology[8]

Getting a grasp of what a new field of research is about, is one of the problems which RFOs have to solve if and when they want to target it for funding. In order to provide a preliminary idea of the new field and how it posed challenges to RFOs, a brief introduction is in place.

In *Introduction to Nanot*echnology, Poole & Owens (2003) introduce the field as follows:

> " The prefix nano in the word nanotechnology means a billionth (1 x 10-9). Nanotechnology deals with various structures of matter having dimensions of the order of a billionth of a meter." (p. 1)

Many if not all descriptions of nanotechnology agree on this and point out that at this scale individual atoms can be 'seen' and that materials at this scale may behave differently from the same material in bigger dimensions. This behavior is not well understood and hence interesting for research. It also provides the potential to develop new applications which may solve problems in daily life or improve welfare.

Descriptions of nanotechnology usually stress its interdisciplinary or multidisciplinary character which incorporates for example physics, chemistry, molecular biology and electronics. The lists of disciplines vary. A report published by the Royal Netherlands Academy of Arts and Sciences mentions

[7] Other countries also permanently support research institutes, but funding comes directly from ministries. In some countries both direct funding and funding via RFOs occurs.

[8] This thesis uses the word 'nanotechnology' to refer to both nanoscience and nanotechnology, unless a particular actor's view on the distinction is discussed.

physics, chemistry and biology (Study Group on the Consequences of Nanotechnology, 2004, p. 15). The US National Nanotechnology Initiative mentioned physics, chemistry, biology and material sciences while indicating that more disciplines are involved (NSET, 2000). The Royal Society and the Royal Academy of Engineering (2004, p. 7) describes the range "from chemistry, physics and biology, to medicine, engineering and electronics".

Besides the range of disciplines involved, also the range of potential applications is wide. For example, in 1996, the UK's Parliamentary Office of Science and Technology (Hirst, 1996, p. 4 - 17) identified the following fields and application areas, among others:

- IT, electronics and computing: nanotechnology may offer further miniaturization of electronic components on a chip beyond the limit in the range of 10-100 nm to the 'ultimate limit' where a single electron represents a single bit of digital information; hard disc manufacturing involves smoothing of surfaces, magnetic coating and high precision positioning of read/write heads, which all can benefit from nanotechnology; entire new types of mass data storage such as magneto-optic crystals allowing holographic storage, or engraving text and images on nanoscale for archiving purposes. Sensors and transducers ('electronic noses') to measure gases or pollutants in the environment or to control quality in food production may profit from advances in surface science so that they can be mass produced at low prices. New types of sensors can be possible where larger scale versions could not exist, such as robust but unobtrusive temperature and flow meters inside engines or inertia navigation systems robust enough to guide oil-drilling bits.
- Manufacturing industry: nanometer structuring of surfaces leads to less friction and wear in turn effectuating higher efficiency and reduction of pollution. Examples can be found in fuels systems and combustion process in the automotive industry, turbine manufacturing in aerospace industry and ships' propellers in marine engineering; better understand of solids with nanoscale crystal sizes lead to new kinds of ceramics with application tailored properties.
- Chemical and Process Engineering: better monitoring and more accurate control of existing processing plants, understanding of molecular interactions at surfaces offer potential for 'designer' catalysts thus expanding the available range of chemical reactions.; 'lab-on-a-chip' approach may offer a new way of designing industrial chemical plants.
- Biology and Medicine: minimally invasive surgery can furthered, for example in eye surgery, repair of nerve tissue or replacing damaged nerves with artificial ones or restoring hearing or sight via micro-implants; in pharmaceutical and genetic engineering lab-on-a-chip can offer new methods of analysis and production tools for pharmaceuticals, nanotechnology offers new ways of delivering drugs and nutrients to selected spots within the body.

A list of historical developments that are considered highlights of the history of nanotechnology can meanwhile also be distinguished. Some variety exists but often some of the following are listed.

Norio Taniguchi of the University of Tokyo coined the term nanotechnology in 1974 to indicate the ability of engineering materials at the nanoscale.

In 1981, Gerd Binnig and Heinrich Rohrer invented the scanning tunneling microscope. With this microscope, it is possible to 'see' individual atoms on a surface. Because the wavelength of visible light ranges from around 380 to 750 nanometer, atoms cannot be seen with the aid of lenses and light. Scanning tunneling microscopes probe or scan a surface to detect the presence of atoms and transforms its readings into a visualization. With these tools and later variants it also proved possible to manipulate the atoms, that is move them around on the surface. The invention is considered a ground breaking tool for the development of nanotechnology research. Binnig and Rohrer received a Nobel Prize in Physics for their invention in 1986.

In 1985, Robert Curl, Harold Kroto and Richard Smalley discovered the so called fullerenes, sphere shaped molecules, consisting of 60 or 70 carbon atoms. They received the Nobel Prize in Chemistry in 1996 for their discovery. In 1991, nanotubes were discovered by Sumio Iijima. Nanotubes became of interest because of their electrical properties and potential as building light weight construction material.

Whereas in the 1980s and early 1990s a focus on individual addressable atoms and molecules existed, in the course of the 1990s the field broadened and parts of other (sub)disciplines, such as supra-molecular chemistry and materials research also became included.

Another highlight in the history of nanotechnology is the launch of the National Nanotechnology Initiative (NNI) by United States President Bill Clinton in early 2000. He and his successor George Bush, subsequently invested billions of dollars in the field. At that time, RFOs and governments of some countries already had been investing in targeted programs for nanotechnology, but after this initiative, many others followed. The NNI is not a scientific breakthrough, but it was a major political boost for the field, including an orientation on technology development (Baird & Shew, 2004, p. 150).

This section provides a brief account. As the following chapters show, what nanotechnology means, and in particular its meaning in the context of RFOs and funding programs, changed in the course of time and differed between actors.

1.3 Research issues

Having outlined the central research question and briefly introduced research funding organizations and the field of nanotechnology, the specific issues can be introduced. First however, some choice of wording of the central question, reproduced below, need further elaboration.

> How do research funding organizations respond to emerging fields of research and what is the effect of the response on both the new field and the funding organization itself?

Firstly, the question suggests a dichotomy between what happens in research and what happens in research funding organizations. Indeed, a distinction can be made between actors. So, a research funding organization can be distinguished from other organizations, such as universities, research institutes and ministries. This thesis is driven by an interest in the behavior of research funding organizations, hence they need to be separated out.

RFOs are however as much actors in the collective of actors and activities that is indicated by the word 'research' as universities and research institutes. As science and technology studies over the past 40 years have pointed out, research involves many different actors, not only researchers, and many different activities, not only performing experiments (Hackett, Amsterdamska et al., 2008; Jasanoff, Markle et al., 1995; Spiegel-Rösing & de Solla Price, 1977).

This implies that if a new field of research emerges, then this is the work of many different actors, including RFOs. Still, the research question uses the verb 'respond' because RFOs in general do not launch new fields of research but support developments that other actors have initiated. As pointed out above and as is documented in the case chapters, RFOs lag behind through their operational practices: they fund projects or programs that others have proposed and they develop priorities by aggregating ideas and input from many actors, mostly but not only from researchers.

Secondly, the question mentions effects of the RFOs' actions on the new field. This needs qualification. Because the RFOs and their behavior are the focus of this thesis, the developments in research are not systematically followed. However, from the design of funding programs and other behavior of the RFOs, potential effects on research can be derived.

A third issue which needs further explanation is the question what constitutes a field of research? As indicated at the beginning of this chapter, identifying a field of research became a task and a problem to RFOs. It implies that they also were the ones who had to determine what constitutes a field of research. So, in this thesis, it is left to the RFOs and other actors to determine what constitutes a new field of research[9].

A field under construction

In Section 1.2, I was careful not to introduce a description of nanotechnology as a given but considered how many definitions describe nanotechnology, and pointed out that its definition changes in the course of time. Nanotechnology is as it were 'under construction' and although some stabilization may be visible, definite closure is not. This poses potential problems for RFOs. If it is unclear what the field is about, then how does one know what to support under the label of nanotechnology. Thus, an issue addressed in this thesis is:

> How do RFOs respond to an emerging field when its definition is 'under construction'?

It touches upon a little investigated aspect of RFOs, which in part addresses questions of how RFOs respond to developments and in part focuses on particular problems of vaguely or ambiguously defined fields of research.

If RFOs are in the business of identifying new research fields for financial support, then how do they do this? Assuming that RFOs do not invent new fields out of the blue, RFOs would somehow need to scan or be in touch with the developments going on outside, i.e. in research institutes, universities, companies, ministries, and other RFOs. Which mechanisms and procedures do they have in place and how do they focus their attention on what and on who?

Another issue is how they process their observations into priorities or topics for funding programs. Which mechanisms and procedures are in place? Which actors are involved and how did they become involved? When, how and why did RFOs prioritize the new field of nanotechnology?

Although these questions can be posed as separate issues, answers may show that they cannot be distinguished in practice. For example, if those involved in scanning developments are the same who propose priorities and develop programs.

If actors are using different definitions or descriptions of an emerging field, then particular problems may occur to the RFO. If it is unclear what the new field is about, then it may also be unclear who the experts of the field are. This causes some circularity as far as the RFO depends on these experts to define the field.

Another issue is that if actors differ of opinion about what constitutes the new field, the RFO has to make its own choice about the outlines of funding programs. How does it under these circumstances make such choices? This concerns issues of content of the field, but also issues of research infrastructure

[9] This is issue is conceptualized in Section 2.3 on p. 31 et seq.

such as availability and geographical distribution of research capacity in universities and research institutes, education of researchers, presence of industrial users, facilities and equipment. For example, is enough research capacity available in a country in view of a particular description of a field?

In general, non-closure on the definition allows the RFO some room for maneuver and to develop its own definition of the field. Because as long as the field's definition is malleable, the RFO is more or less free to bring in its own considerations and interests, which not necessarily have to be 'scientific' but may have to do with its own survival, financial interests or its position vis-à-vis other RFOs. The field as addressed by a funding program thus is open for all kinds of influences and arguments. So, an emerging field of research may offer problems as well as opportunities for the RFO.

At the point when an RFO develops its own definition, publishes it and develops funding programs around it, becomes an actor in the apparently still ongoing struggle for the meaning of nanotechnology.

An interdisciplinary field challenging disciplinary divisions in RFOs

The first page of the introduction already introduced the challenge interdisciplinary fields pose to disciplinary organized RFOs:

How do RFOs respond to the interdisciplinary character of a new field?

The question captures at least two issues. The first is how and where is nanotechnology located within a disciplinary organized RFO or set of RFOs? One solution would be to cut the field into disciplinary pieces. If they did, then how did they try to coordinate efforts? A closely related question is which overarching or interdisciplinary structures RFOs use to address nanotechnology? Did they develop ad hoc solutions for the field of nanotechnology? If they did develop such solutions or solutions to internally coordinate nanotechnology then that could be considered an effect of the response on the RFO itself.

The second issue relates to the organization of research in universities and research institutes. They are also disciplinary organized. How did RFOs attempt to coordinate nanotechnology research across those borders? This delves into subdivisions made within nanotechnology funding programs, the design of funding instruments within programs and requirements for project proposals.

Research by Dijksterhuis, Van der Meulen and myself revealed that biotechnology's interdisciplinary character was problematic to the Dutch Nationale Raad voor Landbouwkundig Onderzoek (NRLO - National Research Council on Agricultural Research). NRLO was not an RFO but a coordinating intermediary organization. It organized a host of topical committees consisting of researchers, research leaders, representatives from the Ministry of Agriculture and Fisheries, and representatives of the agricultural industry. The committees were organized in branches for animal production, plant production, processing and market, and land and nature management. When biotechnology emerged as a field, it proved difficult to locate it within one particular branch and internal coordination between NRLO's branches and committees asked some effort and did not always go smooth (Dijksterhuis & Van der Meulen, 2007, p. 131 - 162).

Because NRLO was a coordinating committee which was based on voluntary participation, it may be suggested that its coordinating role could only be limited. However, a governmental funding program on biotechnology, the so called IOP-b[10] which ran as two consecutive programs in the 1980s, also experienced difficulties. Its final report concluded that during the first IOP-b, coordination between groups was weak and as a result the biotechnological research was fragmented. This, the report argued, was too inefficient and caused overlap. It observed that the mono-disciplinary character of many research institutes collided with biotechnology's interdisciplinary character (Niebling, Pourier et al., 1990, p. 36 - 37).

Facilities and equipment

The need for facilities and equipment to do nanotechnology was clear from the start. Scanning tunneling microscopes require an environment free from vibration and free from dust and other particles. Also, other equipment for nanotechnology research can be costly because of requirements of extreme conditions and nanoscale precision. Compared to for example accelerator facilities used in high-energy physics, equipment for nanotechnology does not require similar long time planning and is of a more distributed character.

Having access to expensive equipment may be required for some types of research and may gain researchers competitive advantage over their colleagues. Financing expensive equipment and facilities to store and operate them is one of the more complicated issues in research organization and funding. They not only require large investments to acquire them and build them, but operational costs, such as costs for energy and technicians, have also to be taken into account. Because of these costs, individual universities or research institutes may not be able to simply buy them from institutional funding. They may need to apply for support at RFOs or Ministries. These parties might be willing to

[10] IOP was the abbreviation for Innovatiegericht OnderzoeksProgramma (Innovation-oriented research program). IOPs were introduced by the Minister of Science Policy in 1979 and financed cooperative projects of public research organizations and private companies. The first IOP was the one for biotechnology.

provide it, but arriving at such a decisions may take years because budgets need to be made available and national priorities set. Such time consuming procedures may in turn make the investment less worthwhile because of developments in research. This delay adds to the building of facilities and the final acquisition of equipment. When support from national sources becomes available, the providers may require that the funded equipment or facilities be shared with other institutes. This may then solve the financial problem but would remove competitive advantage. Thus, a complicated mix is in place of local actors with local interests, national actors and their interests, and lengthy procedures.[11]

The basic issue here is:

> How did RFOs respond to nanotechnology's requirements for equipment and facilities?

This also includes: did the field trigger RFOs do deal with these issues differently? And if so, how?

Societal demand for closer relations between industry and research

The first pages of this chapter introduce a pressure from governments on RFOs to address societal relevance in their funding activities. This pressure called for legitimation of public spending on research in a wide variety of ways. For example research into the functioning of human or animal tissues could be legitimated in terms of its benefits to human health and historical research in terms of preservation and understanding of national culture. Governments seemed particularly interested in the benefits of research to the national economy. They became interested in research in or leading to technology development in order to improve production processes and/or to arrive at new products. They wanted to 'see' such relations and were ready to invest in particular in projects and programs in the natural and engineering sciences aiming for knowledge or technology transfer from public research organizations to companies. They wanted to see universities and research institutes to cooperate more closely with industry and be aware of the potential of their intellectual property rights. (Guston, 2000; Johnson, 2004; McCray, 2005) In addition, in the course of the last decades, governments in particularly of western European and North American countries became convinced that technological development and knowledge based sectors in the private domain

[11] Although inventories of funding needs are made regularly, the problem of equipment and facility funding is under-analyzed. The most recent international overview is Irvine (1997). Duncker (1998) investigated the MESA+ institute at the University of Twente in the Netherlands and Hallonsten (2009) delves into the politics and practices of synchrotron radiation facilities.

had become the major source of economic growth for their countries. They could no longer compete based on profitable mass production with cheap labor countries elsewhere in the world and saw this as their only option.

Nanotechnology rides these historical waves. Descriptions of nanotechnology often stress the field's application orientation and its wide range of potential application areas. For example, the NNI report that president Clinton forwarded to the US Congress discusses materials and manufacturing, electronics and computer technology, medicine and health, aeronautics and space exploration, environment, energy, biotechnology, agriculture and national security (IWGN, 2000, p. 17 - 20). It simply claims "Technology is the major driving factor for growth at every level of the U.S. economy. Nanotechnology is expected to be pervasive in its applications across nearly all technologies." (IWGN, 2000, p. 20)

Often descriptions also address nanotechnology's relevance to basic science: what goes on at the nanoscale is not fully understood. Staying with the NNI report:

> " ..., we are just beginning to understand some of the principles to use to create 'by design' nanostructures and how to economically fabricate nanodevices and systems. ... Each significant advance in understanding the physical/chemical/bio properties and fabrication principles, ... , is likely to lead to major advances in our ability to design, fabricate and assemble the nanostructures and nanodevices into a working system." (IWGN, 2000, p. 16)

Note how in this quote understanding of properties is closely related to economically viable production of applications.

With this historical background and such an understanding of nanotechnology, the fourth issue reads:

> How did RFOs respond to changing societal demands of science's relation to industry when promoting nanotechnology?

How did they design their funding programs for nanotechnology? How did they position and legitimated them? How did they fill in project funding instruments within these program so that basic understanding of what goes on at the nanoscale and indeed leads to economic progress?

1.4 Structure of the thesis

To address the research theme and issues, a comparative case study approach was selected, guided by a conceptual frame. Chapter 2 discusses four theories which provide the frame and concepts necessary to address the research questions. These are principal-agent theory which addresses the RFOs' intermediary position between research and government, boundary-work theory which deals with the demarcation of science and its disciplines, the theory of boundary organizations which combines the first two, and resource dependence theory which provides an overarching frame work.

Chapter 3 sets out the research design. In a first round an inventory was made of RFOs in 9 countries and their responses to nanotechnology. The basic findings are presented in Chapter 4. The set forms a base for selection for further in depth study, and also functions as check for conclusions drawn in the case comparison chapter.

From the first round set, RFOs and their responses were identified in 4 countries for in depth study of these responses. They are the topic of Chapters 5 to 8. Chapter 9 compares and aggregates the findings from these chapters in order to arrive at more generic insights that surpasses individual cases, and it identifies a pattern of stages that describes RFOs' responses to the new emerging field. While invoking resource dependence theory, it also claims that it is a necessary pattern of response.

2 Conceptual frame

This chapter sets out a conceptual frame to structure the answering of the research question. For this purpose, four theories are considered (Section 2.1) and evaluated for use.

The past two decades a number of authors have explored and developed principal-agent theory for the study of the relation between government and research and in particular to the role and position of intermediary organizations therein. Although it is well suited for that, it seems less suited to address the research question of this thesis. The theory of boundary work considers how actors demarcate science from non-science and can also be used to study how they demarcate different disciplines. Thus it seems suitable to address parts of the research question, in particular those dealing with nanotechnology's interdisciplinary character. It is less suitable than principal-agent theory to characterize the RFO in its context and to explain why an RFO responds as it does. The third theory under consideration, the theory of boundary organizations, points out the complementarity of the first two. The combination works well but still lacks means to address organizational and institutional aspects of an RFO's response to a new field of research.

The fourth theory is resource dependence theory. Its central argument is that in order to survive, an organization needs to manage its dependency on resources provided by other actors in its environment. Besides focusing on concrete actors, it tells the analyst to follow the resources and the resource dependencies between actors. It serves as an overarching theory which allows close connections to principal-agent theory and boundary-work theory.

By identifying essential resources and their providers, resource dependence theory allows a similar characterization of an RFO's intermediary position as principal-agent theory (Section 2.2). In addition, because principal-agent theory is a contractual theory and resource exchange is contract-based, explicitly or implicitly, the two are complementary. Thus concepts from principal-agent theory can be used within the framework of resource dependence theory.

With the notion of environment enactment, resource dependence theory pays particular attention to how an organization knows its environment. It has a social constructivist stance in the matter which I propose to take a step further by inserting the notion of boundary work and demarcation of research (Section 2.3). In addition, environment enactment provides additional insight in issues of information asymmetry which play a central role in principal-agent theory.

Finally, a new emerging field of research can be understood to involve changes in availability of resources to an RFO at some point in time (Section 2.4). Responding to such changes (Section 2.5) is essential to an RFO's survival. Thus, the research question can be addressed and RFO's responses can be understood through resource dependence theory.

In all, resource-dependence theory suffices as an overarching theory, but needs further detailing with concepts derived from the others. By showing how it can be applied to RFOs, this chapter also further explains the structure and functioning of RFOs, internally as well as in context.

2.1 Theories for the study of RFOs and their responses to emerging fields of research

Principal-Agent theory

Moe (1984) merged economic theories, including a principal-agent model as developed by Ross (1973) and Spence & Zeckhauser (1971), into a what he, Moe, called 'new economics of organization'. Principal-agent theory deals with the contractual relation between a principal, who buys a particular good or service, and an agent, who delivers the good or service. Such a relation is haunted by problems that stem from an information asymmetry that exists between the principal and the agent. One problem for the principal is that of adverse selection: how can he be sure that he finds the best agent to deliver a service or good? Another problem, called moral hazard, is that after the contract has been made, the principal does not know whether the agent does his best. He may simply trust the agent or implement some kind of monitoring system to collect information on the agent’s performance. Moral hazard also can be a problem to the agent who may find it difficult to convince the principal that he is indeed doing his best. The third major problem occurs when a principal pays for a group effort without being able to measure the individual agents' respective contributions. The agents may be tempted to shirk. Solutions to all three problems can never be perfect, because information about the agent's behavior can in practice only involve proxies. Monitoring systems can be costly and extending them may cost more than the principal gains. (Moe, 1984, p. 750 - 755)

About 10 years after Moe introduced economic approaches into political science, Braun (1993) applied the resulting principal-agent theory to intermediary organizations in research policy making, incorporating elements from Sofsky & Paris (1991), Coleman (1990) and others. He did so by pointing out the triadic structure in systems of research policy making. In it, mission agencies[12] are agents to the political system, which mediate between this principal and the third party, the scientific system. To live up to its principal's expectations, the agent relies on performance by the scientific system, and thus the agent must be recognized by the third party.

> "Only if he or she gives in to the demands from the third party and only if he or she is able to defend those demands in discussions with the principal can he or she probably achieve the cooperation of the third party necessary for his assignment and the gratitude on the side of the third party that guarantees recognition." (Braun, 1993, p. 140 - 141)

Thus, the structural dilemma of mission agencies is that to promote its principal's interests, it also has to promote the scientific system's interests. Braun applied his analysis to a specific group of RFOs, but this dilemma is in varying degrees central to the functioning of all RFOs.

The idea of applying principal-agent theory was soon picked up by others, applied more widely and in different ways. Guston (1996) applied it to the general issue of public research policy. Van der Meulen (1998) modeled the principal-agent relation between government and research as a policy game in which both principal and agent optimize on 'utility', that is, their financial and other benefits. Caswill (1998), Director of Research at the UK Economic and Social Research Council, framed a number of research policy issues in principal-agent theory.

Van der Meulen (2003) reframed Braun's triadic structure into a constellation of government as principal, research performers as agent and research councils as intermediary. In addition, he identified multiple configurations in which the intermediary is aligned more closely with the principal or the agent, or has a middle position. When users are involved, a fourth configuration can occur. Shove (2003) reframed Braun's triadic structure into two principal-agent relations, one between government and research council and one between the research council as principal to research.

In October 2003, *Science and Public Policy* published a special issue on principal-agent theory in research policy[13]. Also, in recent years, principal-agent theory received attention (Fernández-Carro, 2007; Gulbrandsen, 2005; Klerkx & Leeuwis, 2008).

As the above indicates, principal-agent theory is particularly useful to analyze the structural situation of RFOs as an intermediary between government and

[12] With mission agencies Braun referred to funding agencies which were "to promote and execute mission-oriented basic research to improve the transfer of basic scientific knowledge and its application in a specified area (such as health, military technology, agriculture, nuclear energy ...)." (Braun, 1993, p. 142)

[13] Besides the two already referenced, the special issue also included Braun (2003), Braun & Guston (2003), Caswill (2003), Guston (2003) and Morris (2003).

research. Its main drawback is that it is a theory about a relation between parties, but offers no instrument to address changes in these relations. In particular, it offers no instrument to address the main issue of how RFOs respond to changes in their environment. What is needed is a theory which addresses both the intermediary position of RFOs and their responses to changes in research and government.

Boundary-work theory

The central research question asks how RFOs respond to an emerging field of research. One strategy to approach this question could be to specify what may constitute a new research field, for example by describing the field's area of interest and research questions, and then identifying its main institutions, such as its journals, its professional associations, its networks and their activities, including for example its main conferences. The strategy might also identify the main research groups involved in the new field and the main industries. Next, the strategy would retrace the RFOs' dealings with the identified field, the institutions and practitioners.

Such a strategy suffers from a finalistic approach in that it does not allow the RFO to determine itself what an emerging field is. The problem of responding to an emerging field is that it is new, small and unclear. At some point in time, there may not yet be salient institutions which the RFO can identify. Moreover, it may not be clear what type of institutions are the salient ones. For example, in many fields, journals are the authoritative means of communicating findings, but in some fields, such as computer science, conference proceedings are considered more important.

Thus, to study RFOs responding to an emerging field, one has to adopt a strategy that leaves the identification of a new field to the RFO. For this, the theory of boundary work, as introduced by T. Gieryn is useful. Boundary work is a rhetorical style : “the attribution of selected characteristics to the institution of science ... for purposes of constructing a social boundary that distinguishes some intellectual activity as non-science” (Gieryn, 1983, p. 782) It occurs when science’s cognitive authority and the accompanying credibility, prestige, power and material resources are at stake. Science is conceptualized as a social space, which boundaries need to be marked and which remains “empty *until* its insides get filled and its borders drawn amidst context-bound negotiations over who and what is 'scientific' ” Gieryn (1995, p. 405 stress in the original). In other words, it remains empty until its boundaries are recognized, and recognition means that for example authority is granted and/or resources made available to what is within the boundaries.

The same rhetorical style is also useful for demarcating disciplines, specialties or theoretical orientations (1983, p. 792). This is how boundary work provides a perspective on the research question. A new field of science does not simply emerge, its proponents demarcate it as a new space. They do so by attribution of characteristics, i.e. by defining it or describing it, showing how it is different from and relates to existing fields and to the world outside science. RFOs may come in touch with these proponents, may acknowledge the demarcation by deciding to set aside budget to fill the space with people, equipment, and other means to do research. Through this response, RFOs provide the new space credibility and authority.

RFOs play two roles here. They are the audience for proposing researchers who perform boundary work. When they launch a funding program, they become proponents themselves. Depending on the way research programs are developed, RFOs may not necessarily passively accept what is offered to them, but may actively develop their own demarcations of the new field. Moreover, their demarcation has some additional force because their nanotechnology programs finance only the research that fits their description of the field.

By tracing how researchers and other proponents of nanotechnology approach RFOs with demarcations of the new space, and how RFOs do their own boundary work, the finalistic trap is partially circumvented[14].

The advantages of boundary-work theory are clear, but it also has its drawbacks. Its focus is on rhetoric and it explains when it occurs, but it focuses less on the non-rhetorical issues. One such issue of interest for the research question concerns institutionalization in the wake of successful boundary work. Once boundaries are accepted or at least are not under severe attacks for some time, and the space inside becomes filled with authority, credibility and resources, then organizational structures such as university departments, research organizations and RFOs are being built. They acquire a particular organizational shape and momentum and entangle with other aspects of institutionalization of the new field. This includes the accepted boundaries but also rules for performing research and behavior inside the boundary and interactions between inside and outside.

When the RFO is confronted with nanotechnology's interdisciplinary character, this may produce a problem when it has a disciplinary organizational structure or remit. An RFO may solve the problem through its own demarcation of nanotechnology, a rhetorical strategy, or for example by changing its structure. The latter solution can however not be addressed with boundary-work theory.

[14] Only partially because nanotechnology is still selected with the hindsight knowledge that it has grown into a well financed field.

Boundary organizations

D. Guston (1999, 2000, 2001) developed a theory of boundary organizations which explicitly combines the "empirical nuance" of boundary-work theory and the "structure to the thick boundary description" provided by principal-agent theory (Guston, 1999, p. 87). Boundary organizations have three characteristics:

> "1. they provide a space that legitimizes the creation and use of boundary objects and standardized packages;
> 2. they involve the participation of both principals and agents, as well as specialized (or professionalized) mediators; and
> 3. they exist on the frontier of two relatively distinct social worlds with definite lines of responsibility and accountability to each." (p. 93)

Boundary objects and standardized packages are concepts developed by Star & Griesemer (1989) and Fujimura (1992) respectively. The two have some differences and similarities not discussed here, but revolve around artifacts that travel between two social worlds and thus cross their boundary.

Boundary organizations show different faces to politicians and government's policy makers on the one hand and researchers on the other and Guston documents such practices for the Office of Technology Transfer and the Office of Research Integrity at the US National Institutes of Health (Guston, 1999). He suggests that boundary organizations can be found elsewhere on the science-politics border.

The concept of boundary organizations points to a complementarity of boundary-work theory and principal-agent theory. Boundaries between social worlds are subject of boundary work which is flexible and adopted to circumstances, thus may not be consistent and therefor sometimes difficult to follow. However, once boundaries are being accepted, resources and authority fill the space inside, and as pointed out in above, they become entangled with further institutionalization. Principal-agent theory may be used to model this, but as pointed out above, it has its drawbacks as well.

Resource dependence theory

Pfeffer & Salancik (1978) introduced resource dependence theory as a new approach to the study of organizations. It stresses that organizations are intricately and inescapably bound to their environment, which contains the resources that they need in order to survive. To obtain them, the focal organization depends on other organizations that control these resources. Their willingness to provide them is dependent on how effectively the focal organization lives up to their demands. So, the survival of an organization is dependent on how well it manages external demands, either by influencing the demands or by living up to them. Because in practice, environments and the availability of resources change, there is an ongoing problem to the organization. (Pfeffer & Salancik, 1978, p. 1 - 19)

Resource dependence theory not only focuses on how the organization acts towards its environment, but also on how it perceives its environment. The organization acts upon an image of its environment, which the organization internally creates. This so called 'enacted environment' depends not only on the organization's environment but also on its information system, which basically refers to the organization's internal structure. It determines which parts of the environment are seen and it structures the enacted vision. (Pfeffer & Salancik, 1978, p. 12 - 14, 70 - 83)

Through its focus on resource dependencies, the theory allows to characterize the intermediary position of RFOs between research and government in a similar way as principal-agent theory does. Principal-agent theory has its roots in contractual theory, which involves the exchange of financial resources in return for other resources or performing certain tasks or services. In the application of this theory in research policy studies, this exchange remains a central element. Resource dependence theory does not require the analyst to identify principals and agents. Instead it speaks of resource exchanges between the focal organization, here the RFO, and actors in its environment.

The principal's right to enforce certain behavior from the agent through monitoring, a right the principal buys with resources, is mirrored in resource dependence theory's notion of effectiveness. Resource providers only provide their resources to the focal organization if the latter is effective in the eyes of the provider. Because there is an exchange of resources there is also a mutual evaluation of the other party's effectiveness. Thus, resource dependence theory also allows conceptualization of the RFO's dilemma outlined by Braun's quote above. The details of RFOs' resource dependence situation and how this provides an understanding of its intermediary position are set out in Section 2.2.

Besides to characterize RFOs' position, resource dependence theory also provides a framework to address the research question because it focuses on organizational responses to changes in its environment. A new research field constitutes a change in an RFO's environment. Resource dependence theory focuses on changes in the availability of resources. At first sight and when one pays attention to availability of financial resources, this dependency is not clear. After all, RFOs receive budget from ministries and ministries are not the location where a new field of research emerges. However, when other types of resources are taken into account, it becomes clear that important ones are provided by researchers and through these, a new research field constitutes a change in an RFO's resource dependency situation, as is elaborated in Section 2.4.

Because resource dependence theory is an organizational theory, it addresses practicalities which boundary-work theory overlooks conceptually. Its disadvantage is that it does not address the rhetorical issue of demarcation of a new field. Fortunately, its constructivist approach of environment enactment offers an opportunity to complement it with boundary-work theory, as detailed in Section 2.3.

Summarizing, resource dependence theory combines the possibility to conceptualize the RFO's intermediary position, to investigate its response to the emergence of a new field in its environment, and it complements the empirical nuance of boundary work. Therefor, it is a good overarching theory to address the research question, although some modifications are necessary and a detailed understanding of RFOs in terms of this theory is needed.

2.2 RFOs' resource relations

RFOs' resource dependencies

Resource dependence theory holds that the ability to acquire and maintain resources is the key to an organization's survival (Pfeffer & Salancik, 1978, p. 2). So, to understand RFOs as resource dependent organizations, the main resources on which they depend need to be identified. Resource dependence theory does not define or describe what a resource is. However, the fact that it considers knowledge as a resource (p. 48) implies that not only raw materials, money, personnel and buildings, but also less tangible or countable items can be included.

Four major types of resources can be identified on which RFOs are dependent: money, input from researchers, scientific quality evaluation and labor.

- RFOs are in the business of distribution of money. RFOs, at least the public RFOs that this research focuses on, receive this money from one or more ministries. Most of it is channeled to researchers, and a small percentage is consumed by the RFO itself for operational costs.
- RFOs do not want to randomly spread money around among researchers. They need at least two additional types of resources to prevent that. One is input from researchers. This can have the shape of project proposals or

program proposals, but can also be input during workshops for program development or priority setting and strategy development.
- The other additional type of resource is scientific quality evaluation. RFOs want to make scientifically sound choices about which proposals to finance and which not. As a result of earlier boundary work about the demarcation between science and non-science, the societally accepted norm is that researchers are the ones who can make such choices. Through peer review, researchers provide quality evaluation of their colleagues' project or program proposals, and in general, only proposals with the highest ranking are eligible for funding.
- The latter two types of resources imply an additional resource which is labor performed by researchers. Writing and reviewing proposals and participating in committees and boards can take substantial amounts of time, for which RFOs usually do not pay[15].

Besides these main types of resources and depending on the RFO, RFOs may need additional resources. Some, in particular technology RFOs, are dependent on input from and participation of private enterprises in research projects. Industrialists may be member of boards and program committees. Some RFOs are dependent on input and advice provided by non-governmental organizations (NGOs) for the development of policy plans or funding programs.

RFOs' intermediary position and national RFO constellations

The previous section showed how RFOs are dependent on resources provided by other actors. RFOs however also provide resources to these other actors: they provide financial means to researchers and they may provide input, possibly with scientific approval, for policy development to ministries. This is illustrated in Diagram 1 on p. 24. There is some reciprocity in the exchange of resources and the RFO holds an intermediary position. On closer inspection however, the RFO is more dependent on resources provided by others than vice versa.

The resource dependencies of RFOs for research funding mean that in order to serve the interest of the budget providing ministries, RFOs need resources from researchers. Resource dependence theory holds that the researchers will only provide these resources if the RFO effectively lives up to their demands and these demands need not necessarily be restricted to financing their proposals. This is the resource dependence equivalent of Braun's characterization of the situation of mission agencies[16].

[15] In some cases, when writing a proposal takes an extraordinary amount of time, an RFO may financially compensate the applicants or their organization.
[16] See p. 17.

How far this dependence goes can only become clear when alternative resource providers of ministries, researchers and RFOs are considered. Whereas researchers may have other providers such as universities, ministries, private funds and international sources such as the EU Framework Programs, RFOs have no alternative in principle. In practice, the availability of other providers to researchers is quite low in many countries. Their demand for resources tends to outrun the financial capacity of their employers, which provides the RFOs with a relatively strong position. Regarding the relation with budget providing ministries, RFOs hardly have alternative providers that can provide budget to the same extent as Ministries. Ministries however, do not depend exclusively on RFOs in order to promote research activities. They also can and do fund research in more direct ways through funding of universities and research institutes or through running funding programs themselves.

Diagram 1 shows the basic relations but in the real world RFOs of course have resource relations with multiple researcher performers. In addition, they may have relations to multiple ministries and instead of one, there may be two or more RFOs operating in one country. So different national constellations of resource dependence relations may exists. Diagram 2 shows constellations that can be found in Chapters 4 to 8.

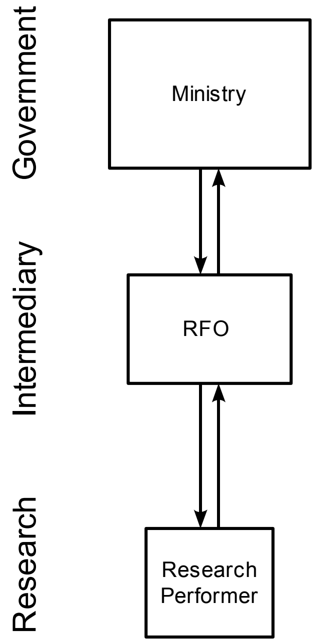

Diagram 1: Basic resource dependence situation of RFOs

A research performer can be an individual researcher, a group, a department, a university or a research institute.

RFOs and their constellations do not drop out of thin air. Rather, RFOs are being established and constellations developed in the course of time. For example, a ministry for science and education may establish one RFO for basic research and later one or more other mission oriented RFOs may be added under responsibility of other ministries. The changes in constellations depend on historical developments, but reflect sectoral divisions of labor between ministries on the one hand and disciplinary divisions of labor in research on the other. The latter may also determine the internal division of an RFO in disciplinary divisions or sub-councils.

A change in a national constellation involves absolute and/or relative changes in national distributions of resources. For example, a newly established RFO offers a new opportunity for funding to particular groups of researchers, thus potentially also moving the resources they provide from an existing to the new RFO. The new RFO may be financed with additional money, but it may also draw away financial resources from existing ones.

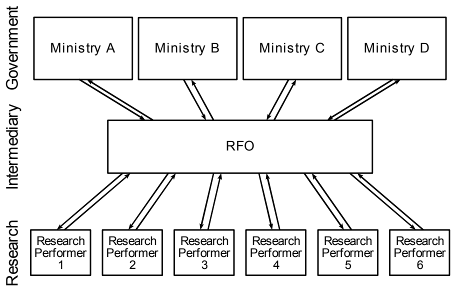

Diagram 2a: Single RFO constellation

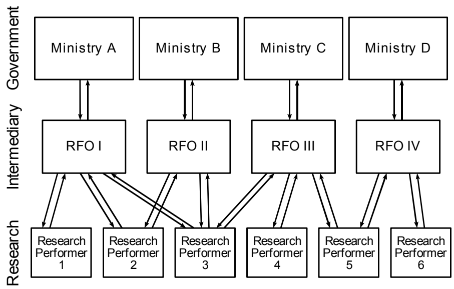

Diagram 2b: Multi RFO constellation

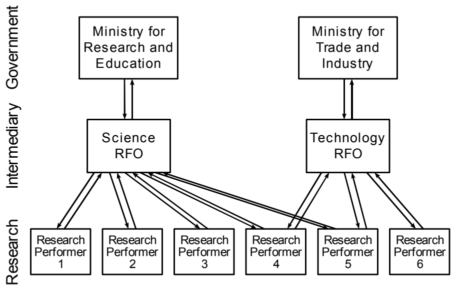

Diagram 2c: Science-technology divide

Diagram 2: Examples of national resource dependence constellations of RFOs

In the course of time, new patterns of resource dependence become entangled with, or appear to be part of, other changes in practices, institutions, and discourse. Such changes may involve divisions of labor in research, government as well as the intermediary layer. These may be divisions within these layers, for example when a new RFO is established next to one or more existing ones, but also between them, for example when RFOs receive new tasks. Such new entanglement may go hand in hand with new demarcations between disciplines, disciplines and sectors, or between science and non-science. Because of such entanglements, changing an RFO constellation may involve considerable transaction costs, which implies that newly created patterns may remain for some time.

One particular constellation for further exploration is the science-technology divide in RFO constellations which occurred when technology RFOs were introduced. It not only serves as an example of a constellation and its entanglements, but also an introduction to research funding practices which are challenged by a field such as nanotechnology which addresses both basic research and technology development and invites to combine the two and bridge the differences between two types of RFOs.

The science-technology divide

When investigating RFOs, it appears that although they all depend on resources, the extent or nature of this dependency differs between RFOs. Current differences in resource dependencies suggest a categorization into two groups of RFOs: the science RFOs and the technology RFOs. Please note that in practical situations the distinction is not always as clear as the following may suggest.

Science RFOs are independent organizations, financed by ministries for science and education[17] but they may receive additional funds from other ministries. Although the science RFOs are financially dependent on their respective ministries for science and education, they are free to finance research as they see fit, be it in varying degrees or concerning parts of their budget. In addition to structural funding, they may receive labeled funding for particular programs or activities from their ministry for science and education or from other ministries.

RFOs put forward multi year strategy plans and annual plans and budget proposals to their ministries and these form the basis of talks and negotiations. Because contacts are on-going and because trends in budgets develop, the process is an iterative one, making it somewhat unclear to which extent ministries influence the plans. Still, compared to technology RFOs, science RFOs enjoy considerable freedom.

Science RFOs show disciplinary organizational structures. One RFO may have multiple disciplinary divisions, or multiple disciplinary RFOs exist next to each other. In some cases, multiple RFOs merged into one whereas the previously existing RFOs remain independent or semi-independent as division.

Science RFOs finance research performed at universities and public research institutes. They are highly dependent on resources provided by researchers for

[17] This at least holds for most countries. Some Asian countries have ministries for science and technology.

priority setting, program management, research proposals, peer review and ex-post evaluation of research.

Technology RFOs receive their budget from ministries for economic affairs which have tight or tighter control over them, to the point where the ministry can commission the RFO to launch a particular program or perform a task. Here too the practical situation can be less clear because the RFO brings in its knowledge about research funding and ongoing developments, which may lead to a relation of negotiation rather than of commissioning.

Technology RFOs have a different set of funding instruments, which has overlap with that of science RFOs. A basic difference is that technology RFOs' instruments may focus exclusively or partially on companies. When they fund research at public research institutes or universities, they require them to collaborate with private parties which are required to contribute financial or other resources to the proposed projects.

Because of the additional target group of private enterprises, technology RFOs may have a double dilemma as introduced by Braun's quote on p 17. They not only have to live up to expectations of researchers from public research institutes and universities but also to those of private enterprises in order to perform their tasks. On the other hand, they depend less on expectations of researchers because they require less resources from them than science RFOs do.

Technology RFOs do not depend on the deliberate input from researchers or companies to develop their programs or priorities, because these are put forward by their financing ministries or developed internally.

Technology RFOs also do not use peer review. Instead, internal experts perform the project selection without the help of external researchers. Although, these internal reviewers often are former researchers or have a degree in the fields of the applications, the review process is not labeled as 'peer review' and not regarded to comply to the scientific 'gold standard'.

2.3 Environment

Three layers of environment

In order to understand how an organization responds to changes in its environment, resource dependence theory distinguishes between three layers of environment. The first consists of basically all that exists, that is all "interconnected individuals and organizations" (Pfeffer & Salancik, 1978, p. 63) that are directly or indirectly related to the organization. The second layer refers to those individuals and organizations that interact directly with the organization. It is through this subset that an organization can experience its environment. I refer to this layer as 'experienceable environment'[18]. It is however not this environment as it is but as the organization observes and interprets it, that influences its actions. This is the enacted environment[19]. Organizations, like individuals, recreate or reconstruct events from their environment. In other words, they respond to self made representations of their environments and events therein.

This three layered structure has implications for the understanding of an organization's response. One is that the organization determines what the enacted environment is by paying attention to certain parts of its experienceable environment and not to others. This means that if the organization pays no attention to something, then this thing will not influence its actions[20]. It then becomes important what influences the process of paying attention, the attentional process (Pfeffer & Salancik, 1978, p. 74). It is mainly determined by the organization's structure, the structure of its information system and by its activities. The information system comprises "reports, statistics, facts, or information that are regularly collected and their pattern of transmission through the organization." (p. 74)

Aggregation machines

How then do RFOs enact their environment? The answer is: in many different ways, including systematic procedures for information gathering in at least their research environment and governmental environment. RFOs with strategic missions may in addition also cover industry and/or other societal sectors.

RFOs maintain regular contact for information exchange and negotiations with budget providing ministries as part of regular budgeting and planning procedures. These are cyclic, complicated and formalized procedures (See for example Van der Meulen & Stroyan, 2001). In addition, RFOs stay in touch with neighboring RFOs both nationally and internationally, and with supra national RFOs such as the European Science Foundation and the European Research Council.

A systematic way of collecting information about developments in research consists of the research funding procedures. Depending on the size of the RFO hundreds, to tens of thousands of applications are submitted annually. The application conditions are checked through structured lists of questions, which

[18] Pfeffer & Salancik (1978) do not provide an adjective.
[19] Pfeffer & Salancik (1978, p. 72) follow Weick (1969, p. 64).
[20] This thing may of course still influence the outcome of the actions.

are supported by the use of forms and on-line application systems connected to back-office proposal databases. In addition, board and committee members bring in knowledge about the research environment, as do program officers through their regular contacts with researchers.

When it comes to tracing and identifying new fields of research in order to develop strategic plans and research priorities, elaborate procedures for information collection are developed. Portfolio analysis of proposal data can be part of that. Researchers are consulted through various procedures, such as consultation of existing boards and committees, but also through additional interviews, questionnaires, workshops, symposia and portfolio analysis.

RFOs thus systematically collect and process substantial amounts of information from various sources from their experienceable environment. They can be labeled aggregation machines. Rip & Van der Meulen (Rip & Van der Meulen, 1996, p. 347 - 348) speak of aggregation as a process of agenda building in national research systems. They point out that intermediary organizations between research and government may participate in such a process. Rip (2000, 2001) speaks of aggregation machines when he focuses on research funding organizations that aggregate project proposals into funding decisions.

Connections can be made with the notion of information asymmetry from principal-agent theory and with boundary-work theory. Two inferences can be made here within conceptual scope of resource dependence theory.

Firstly, with portfolio analysis a connection between an RFO's resource dependency on researchers and environment enactment can be illustrated. Portfolio analysis involves analysis of data that is gathered through funding activities. A call for proposals for a new research program may result in dozens if not hundreds of project proposals which provide all kinds of information about the proposed research, the proposing researchers and their organizations. More data is gathered through all kinds of monitoring and evaluation activities on the granted projects. Through an analysis of the research portfolio officials in an RFO can get an impression of changes and developments in research.

Portfolio analysis is based on input provided by researchers in the course of an RFO's funding activities. This implies that this input is at the same time a resource as well as part of environment enactment processes. Thus, another dependence on researchers is identified and conceptually, the difference between resource and information for environment enactment cannot be made.

A second inference is that the organizational structure and the palette of funding activities have a structuring effect on environment enactment. Depending on concrete practices, the view of disciplinary RFOs or divisions may be limited to their respective disciplines. Only inviting researchers form their own disciplines in consultation activities and limiting portfolio analysis to their own calls and incoming proposals, limit enactment horizons. The more an

RFO limits itself to its own discipline, the less likely it will detect new interdisciplinary fields of research.

Also, within an RFO's remit, programmatic funding of topics will draw out research proposals roughly limited to the selected topics, thus also limiting the horizon of portfolio analysis. It may not be that problematic depending on the total set of funding activities. For example, science RFOs usually also have instruments for open project funding, which because of their open character are likely to detect changes in parts of an RFOs remit not covered by its programmatic funding instruments. Those RFOs which do not have open project funding instruments would need other means to make sure that they see developments outside the scope of their programmatic funding instruments.

Ministries and governments constitute another route through which RFOs can maybe not learn about the emergence of a new field, but be pressurized to take particular action. Possibly, researchers are dissatisfied with the RFOs responses and turn to ministries. Ministries, either through researchers' actions or on their initiative as part of their research policies may require RFOs to develop funding programs for the new field. Or, ministries launch their own funding programs independent of the RFOs, but still indirectly changing the RFOs' resource position.

Information asymmetries between RFOs and ministries

Although RFOs are dependent on resources provided by researchers, both for their funding activities and, partly, for their environment enactment, once they have acquired the researchers' cooperation and once they have their information system in place and start aggregating information, this creates an information asymmetry between RFOs and ministries.

Guston (1996, p. 230) speaks of an asymmetry of information between researcher and those governing research, by whom he meant politicians and government administrators. Because of their aggregating capacity, RFOs could provide a solution to bridge that asymmetry. However, resource dependence theory points out that this introduces an additional step of the Ministries' enactment of the research environment. In other words, RFOs mediate the ministries’ perception of research, thus creating another information asymmetry, viz. one between ministry and RFO.

Arguably, this asymmetry is easier to bridge than the asymmetry between ministries and researchers, simply because fewer actors are involved. Ministries at present[21] lack the aggregating capacities that RFOs have. This means that the

[21] This may not be true for all ministries in all countries, or not for all ministries to the same extent, but in a number of countries including ones discussed in this thesis, ministries have delegated research funding activities to RFOs in the course of the 1990s.

RFO's environment enactment can be considered so important that it warrants labeling it a resource which RFOs provide to ministries.

RFOs however do not have a monopoly on this resource. Universities and research institutes can aggregate data about their respective research projects. Journals and publishers can aggregate research data, not only of published articles but also of articles offered for publication. Individual researchers, depending on their seniority and track record, can be aggregation machines of their disciplines or specialties in themselves simply because they build networks of contacts through their daily work as researchers. However, when these parties' aggregating capacities are compared[22], this will show that RFOs are in a more or less advantageous position for national research funding and policy issues.

Boundary work and environment enactment

With the layered notion of environment and in particular with the concept of environment enactment, resource dependence theory offers a connection point for boundary-work theory. When enacting its environment, an RFO is both in a role of subject of boundary work, viz. the work performed by actors in its experienceable environment, and of performer of boundary work when it translates input into an enacted environment. Here, the RFO's information system and internal organization may influence such enactment as discussed in the first parts of Section 2.3.

Conceptually, another translation, that is, a further active performing of boundary work towards its environment, may take place when an RFO develops a response to an identified emerging field of research.

2.4 Changing environments

Resource dependence theory explains an organization's survival by its ability to manage external demands from actors in its environment that provide the resources the organization needs. The previous section discussed how RFOs know their environment, how they know the demands from external actors and the availability of resources. This section discusses changes in its environment

[22] Which I will leave out, but to provide a start: in comparison with journals, RFOs collect data about plans and ongoing research, not about performed research and RFOs collect national data. Universities can collect data about plans, but would need to cooperate in order aggregate their data, but are in a mutually competitive position which may prevent that. The same would hold for individual researchers.

that relate to the availability of resources and in particular how a new emerging field of research constitutes such a change.

New emerging fields of research as changes in resource dependency

Conceptually, two reasons can lead to important changes in resource availability. Firstly, a resource may become scare or more abundantly available. Secondly, external parties providing the resources may change their demands of the focal organization.

A new emerging field constitutes a change in resource availability to an RFO, but it does so indirectly. The field primarily emerges in research. Thus it constitutes a change to researchers, and possibly, it has or initially has few or only small consequences for their resource needs. Either, they can do the research with the resources available to them or their research organization or university can accommodate for the changes. Perhaps, they do need additional resources from an RFO, but does it provide them through business-as-usual.

This situation may change, for example when increasingly more researchers become involved, or when the field further develops to an extent that existing budgets and funding practices do not suffice. More researchers may want to have access to expensive equipment and/or needs for equipment shift. Another scenario could be that the new field's interdisciplinary character complicates its location within the remit of one RFO, which could result in rejection of applications or referral to another RFO, which in turn may show a similar response, leaving the applicant in a financial twilight zone between RFOs.

In such occasions, a new field may lead to researchers changing their demands of RFOs. They may demand for example new interdisciplinary funding programs which target the new field, bigger budgets for equipment funding or special funding programs for equipment and facility funding. This is where the issue of nanotechnology's high demands for equipment and facilities finds it location within the conceptual frame.

The RFO may or may not live up to these changing demands. If they do not, the researchers may or may not accept that. In the latter case, they may try to find other possible sources, such as ministries or funding sources abroad. They may then also deny the resources they used to provide to the denying RFO. A further consequence may eventually be that the RFO's budget providers draw conclusions as well and withdraw budget or reroute it to other RFOs, research organizations or universities.

National distribution of resource dependencies

Besides changes in the research layer, RFOs also may have to deal with changes in government and in the intermediary layer. Changes in the government layer may be budget cut backs, changing policy ideas and reorganizations. Often, these are not related to emerging fields of research. Some changes are, and these may influence an RFO directly or indirectly.

So, RFOs are dependent on resources provided by actors in the government layer and in the research layer. These actors are or can be less dependent on the RFO than vice versa (See Section 2.2). Just as there may be changes in the RFO's resource situation, there also may be changes to the resource dependence of researchers and governmental actors. For example, a government may launch a funding program, which makes a new source of funding available to researchers. If these resources are not channeled through RFOs then that may be a reason for researchers to turn, fully or in part, their attention to these new sources and accordingly redirect resources they used to provide to the RFOs.

Nanotechnology's interdisciplinary character may cause a similar effect. If a disciplinary RFO for physics launches a nanotechnology program, then that may attract chemists and move their attention away from the neighboring RFO for chemistry.

Both examples point out that RFOs are not only dependent on direct resource providers, but also on the entire national, and to a lesser extent international, distribution of resources. This adds a quantitative element to the analysis of RFOs' dealings with new fields of research.

Changing societal demands in resource dependence perspective

Changing demands and expectations from governments and ministries regarding research constitute a change in an RFOs resource dependence situation as well. In order to remain financed, they need to live up to these demands.

After World War II, the demands were of a more or less generic scope, in line with historical developments that lead the universities and research institutes to be autonomous where their research interests are concerned. But, as pointed out in Chapter 1, governments, parliaments and other actors have put increasingly more pressure on public research organizations and their representatives to show the relevance of their work. Such changing demands affected the resource dependence situation of existing RFOs for basic research.

Governments launched dedicated research institutes, for example for energy research, agriculture or the environment. Also, they established sectoral research councils and technology RFOs, and launched dedicated funding programs themselves. Thus, national distributions of financial resources changed substantially, even when governments made additional budgets available.

These answers were given in addition to the science RFOs. Over the last two decades, some of these were required to address societal topics in their research programs. They used various procedures and organizational structures to develop these programs and receive funding for them.

2.5 Responses

Following Pfeffer & Salancik (1978), when an organization responds to external changes, there are basically two possible directions : internally oriented actions and externally oriented actions.

Changes in an organization's resource dependencies may result from changes in availability of resources and from changes in demands and expectations of resource providers. As becomes clear from the previous section, changes resulting from new emerging fields of research arrive at RFOs as changes in demands and expectations from researchers. Resource dependence theory offers a host of response strategies, but they are not all open to RFOs, being heavily dependent on two external parties. For example, 'vertical merger' (Pfeffer & Salancik, 1978, p. 115 - 123) is partly out of scope. An RFO buying a ministry is not likely. An RFO buying a research institute could be an option if the RFO is able to engage in institute funding. A number of basic responses can be identified.

One type would be to respond to demands in a business-as-usual fashion. Open project funding can take care of small changes in demands. Launching a funding program to respond to demands for more targeted funds would be another. This would include both bottom applications for nanotechnology programs or prioritization by the RFO. Depending on the situation, disciplinary remits may restrict the possibilities and lead to fractioning of the field, but perhaps allow enough space to yield to certain demands.

A second basic type would be to adapt organizational structures to accommodate further reaching demands. For example, RFOs or divisions thereof may decide to launch a common funding instrument to address nanotechnology's interdisciplinary character, to bridge the science-technology divide, or to pool budgets for large scale investments in facilities or equipment. A further reaching variant would be that RFOs initiate a structural adaptation of their organization to address not only nanotechnology but also other fields of research with similar characteristics.

A third basic type of response is strategic influence of external parties, either to mobilize additional resources or to influence external demands. Mobilizing additional resources may in fact be business-as-usual as RFOs annually strife for increased budgets.

2.6 Rephrasing the question

The previous sections present a conceptual frame to study the behavior of RFOs as resource dependent organizations. RFOs' resource dependence situation is outlined; their means to enact their environment, relevant changes in their environment and their basic means to respond are introduced. At this point, the question introduced at the start of the Introduction can be rephrased. The assumption is that the emergence of a new field of science and technology in general, and nanotechnology in particular, changes the resource dependence situation of an RFO. The types of change basically consist of (direct and indirect) demands from researchers and/or demands from government. Such demands are part of an RFO's resource dependence situation because if it does not meet them well enough, these actors may stop providing resources to the RFO or in other ways manage their respective resource problems.

> The main question of this thesis is which type of responses do these changes invoke?

The assumption that there are changes needs a further remark. From a resource dependence perspective it is important to add that RFOs need not to be aware of the changes. Organizations respond only to the extent that the changes become part of the enacted environment. An RFO may not notice the change at all and the "response" or "non-response" if you like, implies that it continues its strategy.

If it does detect changes in its environment then there are several possible responses from a resource dependence perspective. The first is that the RFO already has the means to respond within the organization. Responding to the challenges of the new field is then a matter of business as usual. Things get more complicated for the RFO if the current organization is not able to respond and it cannot satisfy the new demands. In that case the organization needs to adapt, for example by developing new funding instruments that fit the characteristics of the new field of science and technology. Another option is to adapt the organization as such and create a specific unit for the new field, or merge and change existing parts.

Note that organizations, and RFOs alike, often have units or organizational functions to interact with the organizations environment. In other words, it might well be that the organization in one way or another gets involved in the articulation of the demands. This kind of interaction can already be seen as part of the response and a possibility to shape the enacted environment towards the strategic options of the RFO.

3 Research design

By applying an extended resource dependence theory, I want to understand how RFOs respond to the emerging field of nanotechnology with special interest in the four issues identified. Because I am interested in responses of RFOs to a change in their environment, and resource dependence theory points out the relevance of an organization's environment for its survival and functioning, RFOs need to be studied in context. The theory also indicates that their internal structure is important for their environment enactment and their possibilities of response. As there is yet little insight in the range of policy responses towards new fields of science and technology and the role of RFOs in this, a comparative case study approach was used, in which cases were selected in two phases. In the first phase, a broad set of cases was explored. In the second phase, four contrasting cases were chosen for in depth analysis.

The previous chapter identified typical resource needs of RFOs, categorized national constellations and outlined existing internal organizational structures. It identified two basic routes through which RFOs can enact an emerging field, and a categorization of possible responses was provided. Thus necessary conceptual building blocks are in place for a systematic comparison of RFOs and their responses.

One factor complicates such a comparison. Organizational responses are not only a matter of resource dependence structures, but also of changes. New fields of research emerge, develop, and after some time may also disappear. In addition, RFOs and their resource dependence situation also develop unrelated to the emergence of a particular field. Further complexity is caused by dynamics of responses to changes in resource availability, which in turn cause changes in resource availability to other actors, and so forth. Put differently, the independent variables may not be that independent.

Benner & Sandström (2000) take general changes in RFOs' resource dependence situation as their focus of study. They investigate how research council systems in Denmark, Norway and Sweden, responded to changes in political, economic and cognitive environments and use biotechnology as an illustration thereof. Although similarities with this thesis can be found, their primary focus differs from the one adopted here. This thesis focuses on responses of individual RFOs from the perspective of the RFOs, rather then from an external systems perspective.

Still, changes such as Benner & Sandström describe, and dynamics of responses to the new field add to the difficulty of comparing cases. Eventually, dynamics have to be compared, rather than or in addition to structures and responses. This warrants in depth and historical study of cases. The resulting understanding of RFO behavior could thus also have a diachronic character.

3.1 Phase 1

An initial set of countries was investigated in order to acquire a general understanding of the main variables set out above, and of the RFOs main responses to the field of nanotechnology. This served two purposes. Firstly, it was a base to select cases for in depth study. Secondly, the set can be used to at least superficially check the findings from the in depth case studies against a bigger set of cases.

Personal knowledge about responses of RFOs to the emergence of nanotechnology in a number of countries countries, and literature and personal knowledge about existing RFOs and RFO constellations was available. On this basis, an initial set of nine countries was selected which showed similarities and some diversity in terms of national RFO constellations. Countries were also selected because of their RFOs' interesting response histories. European countries were selected in order to have a set of countries with a similar supra-national governance setting, basically consisting of the European Commission's Framework Program and the European Science Foundation's activities. Not all countries were involved in European research policy activities and treaties at the same time. RFOs from Eastern European countries were left out of scope, in particular former Soviet Union countries, because post Soviet era developments may play a particular role. One result of this European criteria is that the United States and Japan were left out of scope although they are well known for their substantial or early investments in nanotechnology. Language issues were a reason not to include South, East and Central European countries. My language skills allow for Dutch, English and German speaking countries, and to a lesser extent French speaking countries to be included.

The countries thus selected were Denmark, Finland, France, Germany, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom.

This first phase, which took about the calender year of 2006, consisted of an inventory of RFOs, their resource relations with ministries and researchers, their internal structure, their main strategies and funding instruments, and their activities targeted at nanotechnology over the past 15 to 20 years. In addition, governments' funding and other nanotechnology activities and main developments in research were collected as well, as they provide an understanding of the RFOs environment.

Most data was acquired from websites and digitally available documents. Additional documents, in particular from the 1990s or before, were requested from RFOs and other sources, but unfortunately not always successful. The documents and webpages included:

- Brochures, implementation plans and evaluation reports of nanotechnology research programs
- Technology assessment and technology radar reports[23]
- Annual reports and strategy documents from RFOs
- Laws, regulations, statutes and other documents describing the internal organization of RFOs and national research funding structures and procedures
- Depending on the events that occurred, additional documents were collected
- Secondary literature about research funding, policy and history of the individual countries and RFOs. The European Commission's TrendChart reports proved a helpful source here[24].
- Secondary STS and research policy literature about national nanotechnology developments.

3.2 Phase 2

During the second phase, four countries were selected because the preliminary findings promised worthwhile answers to the research questions. For each country these reasons are set out in the introduction sections of their respective chapters.

To arrive at a more detailed understanding of how RFOs in these four countries dealt with the field of nanotechnology, phase two's main data sources were interviews. In addition, more documents were gathered during preparations for the interviews and via the interviewees.

The general strategy for selecting interviewees was to identify actors from all three layers of the research model introduced in the the conceptual frame, within RFOs, related Ministries and the research layer. From the research layer, only persons involved in RFO activities and bodies were selected, such as chairs or members of program committees, program applicants or Boards. I am interested in the RFOs' perspective and thus it makes sense to interview only researchers who were in close contact with the RFOs and thus had detailed knowledge of their functioning and can be considered part of their information

[23] Initially the research focussed on a wider range of intermediary organizations.
[24] Currently accessible via European Commission (s.a.-a)
The Erawatch database became available by the end of phase one. See European Commission (s.a.-c)

system. From within RFOs, mostly program managers of nanotechnology programs were approached because they are considered closest to the nuts and bolts of program management and development.

The interviews were semi-structured via question lists prepared in advance. The question lists were developed to arrive at answers to the research questions, which meant that some questions reappeared in all lists. Part of the questions were geared to the reasons for selecting the individual cases.

When interviewees requested this, they would receive the list beforehand. Interviews lasted one to one and a half hour and most were face to face interviews. One interview was a telephone interviews because the agenda of the interviewee had no opening during the planned country visit. During the writing phase, additional information was requested from the interviewees and one additional telephone interview was held. In all, 25 interviews were held with 30 persons. 3 Interviews eventually were not used in this thesis. A list of the remaining 22 interviewees is provided in Section 10.1.

Interviews were recorded with the consent of the interviewees. Summaries of the interviews were presented to the interviewees. They were asked for their approval and given the opportunity to correct them and to add text if they felt so. Only interview data from interviewees who approved of the summary or of the corrected/extended version were used for this thesis[25]. It was also agreed that in case quotes would be used in the thesis, the recorded text would be used and that the interviewee would have the opportunity to see the quote in context and to agree or disagree with its use[26].

In addition to these, background interviews were requested from a researcher in a nanotechnology area and researchers studying research practices and policy. Because of the informal character, these interviews are not used in the case chapters.

The approved interview data was merged with data from documents and websites, in order to build the case chapters and in order to cross check the sources against each other. Cross checking here means a rough consistency check while acknowledging that different actors may have different accounts of what happened and why, and have different frames of reference.

A number of interviewees played roles in multiple funding programs and/or developments, whereas available interview time did not allow addressing all. Here, priorities were made so that all interesting developments were covered by at least one interview. A result was that some developments which could have been discussed with two or more interviewees were discussed with only one.

[25] Initially, the agreement with interviewees from Norway and Finland was that they could approve the use of their interview as it would occur in the final text. Later, I realized that this would lead to practical problems during the writing and finishing of the thesis. These interviewees were asked to agree to the procedure described in the main text, which they all did.

Due to a combination of late delivery of the summary and his busy time schedule, one interviewee could not respond in time.

[26] The thesis uses no quotes from the interviews.

These accounts were compared or backed with document data, but in some cases documents were not available or in existence.

The interview summaries were coded for answers to the research questions and themes that turned up during the interviews. Together with document derived data, reconstructions of developments were created as far as relevant for the research question.

3.3 The chapter protocol

The protocol used to write the case chapters consist of the following items:

- *Outline of and major changes in national research funding organization, main research institutes, prime foci of research and of main national industries.*

  Because resource dependence theory poses that an organization's survival is dependent on its ability to manage resources provided by its environment, this environment should be outlined. Through identifying the RFO's resource dependencies on other actors in its environment, a multi layer situation was identified. These layers should therefor be outlined. In addition, major changes in these structures, in particular during the past two decades, should be included as well so that RFOs' activities can be placed in the right historical developments.

  - Science-technology divide

    Many countries show a science-technology divide in their national research funding structures. Because nanotechnology addresses both basic research and applied research, this poses a challenge to the RFOs.

  - Internal organization of RFOs

    The internal organization is interesting for three related reasons. Firstly, resource dependence theory points out that organizations respond to how they enact their environment and that this is dependent on their information system and internal organization.

    Secondly, not all organizational units in RFOs have the same instruments to respond to developments in their environment, so internal organization in outline shapes possible responses.

Thirdly, one of the identified challenges/research issues addresses incompatibility of nanotechnology's interdisciplinary character and RFOs' disciplinary structure.

- Institutional border-crossing solutions of the first and third sub-bullets

Because nanotechnology crosses and combines categories in some dimensions that structure RFOs and their environment, nanotechnology constitutes a challenge to the RFOs. In case of some countries and some RFOs, institutional solutions to such problems were developed earlier to deal with these challenges as they occurred earlier with other fields.

Ad-hoc solutions developed for nanotechnology are also of interest, but would be dealt with when the responses to nanotechnology are dealt with rather than when national or internal structures are outlined. In particular, a solution to nanotechnology's interdisciplinary character directly provides an answer to one of the issues identified in the Introduction.

■ *Historical development of selected responses to nanotechnology*

During phase one a number of responses to nanotechnology were selected for further investigation. Because the focus is on major targeted responses of RFOs, the focus is on funding programs. Developments leading to the launch of a program and shaping the program are of interest, because they show in addition to structure aspects, how an RFO's information system operates in terms of process and in terms of content. RFOs aggregate, but what do they aggregate and how do they transform input into a response? In particular, the following issues are addressed:

- Who were the main actors and how did they become involved?

Three layers of resource dependence are identified and from within each layer, actors may have reasons to involve themselves, or RFOs may have reasons to involve actors from these layers.
- researchers trying to manage actors in their environment in order to secure resources. They can be applying for program funding through existing instruments, but they can also be more pro-actively pursuing their interests. RFOs may also invite researchers to participate in processes of priority making or program development.
- government policy makers may be trying to bring nanotechnology under an RFO's attention
- actors from within RFOs, doing their regular jobs

- other RFOs or divisions dealing with nanotechnology and trying to mobilize their neighbors in the intermediary layer

These actors can be part of the RFO's enactment process, and they may also be highly influential in shaping the RFO's response. Their notions of nanotechnology are likely to shape or influence the funding program's definition of nanotechnology.

- ◆ How was nanotechnology identified as topic for funding?

If a new field of research is developing in the research layer, then this constitutes a change in the RFO's environment and indirectly also a change of its resource dependence situation. The change initially affects researchers: their focus of attention may shift and their needs for resources shift accordingly and that has consequences for their relation to the RFO. Resource dependence theory points out that the RFO first needs to detect such a change before it can respond to it.

This issue addresses the challenge how to respond to an emerging field when its definition is still under construction. Boundary work plays a role where the 'shape' of nanotechnology is concerned, but also issues of legitimation, relating to the fourth issue, may play a role.

■ *Description of selected funding programs*

Program description can contain the following elements.

- ◆ Which definition of nanotechnology is used and how was it developed?

This addresses the boundary work performed by the RFO through the funding program. The question how it was developed could also be addressed under the historical developments leading to the program, but in order not to fragment the definition issue, it is located here.

- ◆ The program's position in view of societal demand for legitimization of research investments in terms of connections with industrial development

Funding programs constitute one of the means or channels through which RFOs respond to this challenge and to the challenges of nanotechnology. Within funding programs, it is addressed through at least three aspects: legitimization of investments in nanotechnology, stated program objectives, organization of program management, and implementation in funding instruments used within the program.

How funding programs address these issues is closely related to how it positions basic and applied research vis-à-vis each other and vis-à-vis the RFO's position in the national science-technology divide.

- The program's subdivision of nanotechnology

This immediately addresses the issue of how RFOs respond to nanotechnology's intermediary character.

- Budget of the program

Including a brief comparison to other program and overall budgets to provide an indication of the program's relative size and thus of the importance an RFO adheres to nanotechnology.

- Funding instruments within the program

The funding instruments deployed within the program show how an RFO concretely addresses challenges posed by the emerging field of nanotechnology. Besides issues already mentioned above, the section of funding instruments is the only 'location' within a funding program where the challenge of costly equipment and facilities are addressed - if they are addressed.

- *Issues particular to the case*

Cases were selected in view of expected findings with regards to the issues which are addressed through the case protocol. This means that case particularities can be located within the protocol. They may cause particular aspects to receive less or additional stress and more detailed treatment.

4 Outline of responses in 9 countries

This chapter provides an appraisal of the major research funding responses from RFOs and governments to the challenges of nanotechnology introduced in Chapter 1. It also deepens them further through an exploration of descriptions of nanotechnology as they are used in research funding and related activities in the nine countries identified in the previous chapter.

4.1 Funding responses in nine countries

To appraise how the RFOs in the nine countries handled the challenges of nanotechnology, they have to be presented in their historical research funding context. Therefor each of the following country summaries first deals with national research funding structures followed by the main funding responses.

Denmark

The Danish research funding structure had been relatively stable since a group of RFOs was established during post World War II decades. The six were Statens Humanistiske Forskningsråd, Statens Jordbrugs- og Veterinærvidenskabelige Forskningsråd (SJVF - Danish Agricultural and Veterinary Research Council), Statens Naturvidenskabelige Forskningsråd (SNF - Danish Natural Science Research Council), Statens Samfundsvidenskabelige Forskningsråd, Statens Sundhedsvidenskabelige Forskningsråd (Danish Medical Research Council - SSVF) and Statens Teknisk-Videnskabelige Forskningsråd (STVF). These councils operated in the fields of humanities, veterinary sciences, natural sciences, social sciences, health sciences, and technical sciences respectively[27], and were funded by related sectoral ministries.

In 1991, Danmarks Grundforskningsfond (Danish National Research Foundation) was established. This is a capital based RFO which started with a

[27] The official English translations could not be retraced.

capital of DKK 2 300 M and uses revenues to support centers of excellence during 5 to 10 year periods. (Danish National Research Foundation, s.a.-a, s.a.-b, s.a.-c)

In the course of the 1980s, actors grew dissatisfied with the fragmented character of the RFOs' sectoral relations, disciplinary structure, and strong orientation on internal research developments. In 1993, a separate Ministry for Research was launched with an interdisciplinary and cross-sectoral orientation. It used an instrument of large-scale funding programs and initiated cooperation with sectoral ministries and the research councils. This lead to tensions between these actors and to opposition from the universities which saw a breach with the tradition of scientific self governance. (Grønbæk, 2001a)

From 1995 to 1997, the Ministry for Research attempted to reduce the number of RFOs from six to three and to bring them under one board with the ability to launch programs independent from the RFOs. After long debates, parliament rejected the proposal. The Minister then proposed an umbrella organization for the RFOs and this was accepted. This became the Forskningsforum. (Grønbæk, 2001a)[28]

A new law on the organization of research funding came into force on January 1st, 2004. Among other things, the Forskningsforum was abolished and replaced by Det Frie Forskningsråd (DFF - The Danish Councils for Independent research). The essence of the new situation is that a hierarchical relation was introduced between DFF and the six research councils. (Forskningsforum, 2004, p. 3, 6; Sander, 2003) About one year later the six research councils were reorganized into five: Forskningsrådet for Sundhed og Sygdom (Medical Sciences), Forskningsrådet for Natur og Univers (Natural Sciences), Forskningsrådet for Kultur og Kommunikation (Humanities), Forskningsrådet for Teknologi og Produktion (Technology and production sciences) and Forskningsrådet for Samfund og Erhverv (Social Sciences).

The same law also established the Strategiske Forskningsråd (Danish Council for Strategic Research), which was to support research in politically prioritized, thematic research areas. Its main funding instrument consists of program committees for the respective selected areas. Other tasks included foresight, and advice to the Government and other actors. (Sander, 2003, Section 17)

With the exception of the Danish Council for Strategic Research, all RFOs fall under responsibility of the Ministeriet for Videnskab Teknologi og Udvikling (Ministry of Science, Technology and Innovation), as it is currently known.

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[28] Grønbæk (2001a) attributes the Ministry's failure partly to a mismatch between the RFOs bottom up approach towards research prioritization and the Ministry's wish for a more strategic and top-down approach. The Ministry wanted the RFOs to play a more mediating role, rather than a representational role for research. Grønbæk also identified other factors contributing to the failure, such as the fact that the Ministry did not involve the RFOs in the preparations and development of its plans and that the RFOs were well connected with members of parliament. More details in Grønbæk (2001b)

It seems that the Ministry's attempts of the 1990s to bring the then existing RFOs more in line with societal issues and stimulate more interdisciplinary research failed and that the Ministry decided to launch a separate strategic RFO next to the existing ones which could keep to basic research and bottom up funding practices. Probably, under those circumstances, the six RFOs were willing to be under one steering board.

With the exception of Statens Teksnisk-Videnskabelige Forskningsråd's (STVF) participation in the ESF program 'Vapour-Phase synthesis and Processing of Nanoparticle Materials' in 1996 (Forskningsforum, 1997), the Danish RFOs involved themselves not before the United States' National Nanotechnology Initiative[29]. In May 2001, a committee chaired by SNF Council member F. Besenbacher, and vice-chaired by STVF council member J.K. Nørkov, presented the report *Nanoteknologi - i en grænseløs verde*, (Nanotechnology in a world without boundaries - my translation) (Besenbacher, 2001). The next year, both SNF and STVF published their strategic plans for the years 2003-2007 and both identified nanotechnology as a priority area. SNF titled it "Nanoscience - Nanotechnology" (SNF, 2002, p. 24) and STVF "Nanoteknologi - revolutionerende perspektiver" (Nanotechnology - revolutionizing perspectives - my translation) (STVF, 2002).

Also in 2003, Danish political actors made around DKK 135 M available, from a fund which resulted from sales of UMTS frequencies, for a National Effort in Nanotechnology and Nanoscience[30]. Grants were awarded after advice from a purpose built council containing representatives from SNF, SSVF, SJVF and STVF. (SNF, s.a.)

In 2004, the Strategiske Forskningsråd established a program committee for Nanovidenskab og -teknologi, Bioteknologi og IT (NABIIT - Nanoscience, Nanotechnology, Biotechnology and IT) as a follow up on Nanoteknologi - i en grænseløs verde. NABIIT started with DKK 30 M for nanotechnology and DKK 40 M for IT, apparently as separate programs. (Det Strategiske Forskningsråd, 2005, p. 32) One year later, it launched a program on that aimed to integrate all its areas. (Det Strategiske Forskningsråd, 2006, p. 107 - 110)

The Danish science RFOs, that is SNF and STVF, seem to have fractioned the field through their respective strategic plans. Government actions seemed better able to launch more interdisciplinary funding programs which required the science RFOs to cooperate in awarding grants. Also, the Strategiske Forskningsråd which aims to address government policy aims seemed in a better position to address nanotechnology's intermediary character, simply because it is not structured along disciplinary lines.

[29] This should be taken with the reservation that no sources reporting about the pre 1996 period were available in this research.

[30] The source did not specify who made the decision. The money was made available through two decisions made in March and November.

Finland

At present, Finland has a clear science-technology divide in it national research funding structure. Tekes is the technology RFO which was launched in 1983 and financed until 2008 by Kauppa- ja teollisuusministeriö (Ministry of Trade and Industry)[31]. On the science side, the Academy of Finland, financed by Opetusministeriö (Ministry of Education), takes care of project and program funding in all disciplines. The Academy of Finland was establish in the post World War II decades and underwent a major reorganization in 1995 when its seven divisions were replaced by four. One argument for the reorganization was that interdisciplinary programs were difficult to locate in the old structure. (Academy of Finland, 1996; Dresner, 2001, p. 120; Skoie, 2001, p. 36 - 37)

The two RFOs initiated nanotechnology funding programs which bridged the science-technology twice in different ways. These efforts to bridge the science-technology divide were in part driven by pressure from the government layer to arrive at closer cooperation between the two organizations and by reasons of efficiency: the two organizations wanted to prevent double funding of projects which researchers could present either as basic research to the Academy of Finland or as applied research to Tekes.

The first nanotechnology cooperation involved one shared program which ran from 1997 until 1999. The second consisted of two parallel programs, both called FinNano, which started in 2005. Although the programs carry the same name and their respective websites mention collaboration and coordination with the other program, they appear to be different on closer inspection.

France

Until 2005, France had no separate organizations that dealt with research funding. Since the 1950s, research was funded through big sectoral research institutes. Some of these were abolished in the 1980s and 1990s, but a few, such as Commissariat à l'énergie atomique[32], Centre National de la Recherche Scientifique, Institut National de la Santé et de la Rescherche Médicale[33], and Institut National de la Recherche Agronomique (French National Institute for Agricultural Research) still remain. These institutes operate and fund many smaller sub institutes.

[31] As of January 1st 2008, the Ministry was abolished and its tasks transferred to the Ministry of Employment and the Economy which started its operations as of that date. (Työ- ja elinkeinoministeriölle, s.a.)

[32] Originally established as an agency for atomic energy affairs and research. Currently CEA has a wider focus on energy technology, health technology, information technology, and technologies related to defense and national security

[33] A national institute for health care and medical research.

Next to these big research institutes, the French Government operated the Fonds de la Recherche Technologique (FRT) until 2005. This was a fund for industrial research, a number of big research institutes, public private cooperation in research and technology transfer. (Ministère de la Recherche, 2001, p. 24)

In 1999, the French Government created the Fonds National de la Science (FNS) which was meant to finance government priorities, especially when it comes to multidisciplinary research that requires inter-institutional cooperation of research institutes. FNS was operated by the then existing Direction de la Recherche of the Ministère délégué à l'Enseignement supérieur et à la Recherche. (Ministère de l'éducation l'enseignement supérieur et de la recherche, s.a.)

At the beginning of 2005, activities of both FRT and FNS were transferred to the then newly launched Agence National de la Recherche (ANR). ANR seems to hold a middle position in the science-technology divide. It aims to fund research at both public as well as private organizations on the basis of programmatic calls for proposals and peer review. It has "a double mission of producing new knowledge and promoting interaction between public laboratories and industrial laboratories through the development of partnerships" (ANR, s.a.).

The first nanotechnology funding program in France was launched by the French Government in 1999. It was called the Réseaux Micro et Nano Technologies and financed by the Ministère délégué à la recherche et aux nouvelles technologies (the Ministry in charge of research), other ministries and agencies and by industry. They contributed € 32 M, € 17 M, and € 42 M respectively over the years 1999 - 2003. (Direction de la technologie, 2005, p. 54) As of 2005 the program was renamed R3N and handed over to ANR which renamed it PNANO (ANR, 2006, p. 20 - 22; Direction de la technologie, 2006, p. 68). PNANO ran for four years in which it granted more than € 99 M[34] and then was replaced by Nanosciences, Nanotechnologies, Nanosystèmes (ANR, 2008, p. 277 - 278)

Germany

During the past two decades the German research funding organization remained comparatively stable. It is a federation, its states are called Länder, and freedom of research is declared in its constitution. Universities are funded by the Länder with additional contributions from the Federal Government. Besides universities, Germany holds a range of research institutes which receive institutional funding from Federal Government and Länder through four

[34] At the time of writing no figures were available for 2008.

organizations: Max Planck Gesellschaft (Max Planck Society), Fraunhofer Gesellschaft, Helmholtz Gesellschaft, Gottfried Wilhelm Leibniz Gemeinschaft. The Federal Government operates targeted research programs through its ministries, in particular through the Bundesministerium für Bildung und Forschung (BMBF - Federal Ministry of Education and Research) (BMBF, 2005).

Germany has one RFO, the Deutsche Forschungsgemeinschaft (DFG - German Research Foundation) which funds basic research in all disciplines. It receives most of its budget from the BMBF and the Länder, and is free to spend that as it sees fit[35]. In 1999, about 40% of its budget went to individual grants, about 30% to Sonderforschungsbereiche (Collaborative Research Centers), about 15% to Schwerpunktprogramm (Priority Programs), and the remainder to other instruments. (Hackmann, 1999) Currently, DFG has a range of about 40 instruments in 9 categories. Most of them, including the program funding instruments deploy bottom up proposal systems and peer review. One exception is the Excellence Initiative, for which DFG receives additional funding of € 1 900 M in period 2006 - 2011 from the Federal Government and the Länder. These sponsors participate in the final selection after a review procedure made a pre-selection based on scientific quality. (DFG, 2008)

The bottom up approach resulted in a number of granted program proposals, as listed in Table 1. The table reveals that through bottom up application processes, programs for nanotechnology were identified relatively early. It also shows an increase in number in the later years. Compared to many other programs in different countries, the program titles reveal that they address more specific areas within nanotechnology than the usual nano-nized discipline programs. For example, instead of nanomaterials, a program addresses manipulation of materials on the nanoscale.

Netherlands

In the Netherlands a major reorganization was initiated by the end of the 1980s. The then existing foundation for Zuiver Wetenschappelijk Onderzoek (ZWO - Pure scientific research - my translation) was replaced by the Nationale organisatie voor Wetenschappelijk Onderzoek (NWO - Netherlands Organization for Scientific Research). As the new name suggests, NWO was meant to be the national central organization for funding of scientific research, rather than only the pure or basic scientific research. NWO's first board was installed on 1 February 1988. (NWO, 1989, p. 3)

[35] Still, the internal body that is responsible for research funding decision contains 32 representatives from federal ministries and Länder, next to 39 scientific members. (DFG, 2004)

Table 1: DFG funded programs carrying 'nano' in the title, 1996 - 2006

Instrument	Program title	Starting year
Collaborative Research Centers	Struktur und Dynamik nanoskopischer Inhomogenitäten in kondensierter Materie	1996
Collaborative Research Centers	Nanostrukturen an Grenzflächen und Oberflächen	1996
Collaborative Research Centers	Nano-Partikel aus der Gasphase: Entstehung, Struktur, Eigenschaften	1999
Collaborative Research Centers	Manipulation von Materie auf der Nanometerskala	2000
Collaborative Research Centers	Hierarchische Strukturbildung und Funktion organisch-anorganischer Nanosysteme	2001
Collaborative Research Centers	Von einzelnen Molekülen zu nanoskopisch strukturierten Materialien	2002
Collaborative Research Centers	Nanopositionier- und Nanomessmaschinen	2002
Priority Programs	Neue Strategien der Mess- und Prüftechnik für die Produktion von Mikrosystemen und Nanostrukturen	2004
Priority Programs	Nanodrähte und Nanoröhren: von kontrollierter Synthese zur Funktion	2004
Priority Programs	Nano- und Mikrofluidik: Von der molekularen Bewegung zur kontinuierlichen Strömung	2004
Priority Programs	Nanoskalige anorganische Materialien durch molekulares Design: Neue Werkstoffe für zukunftsweisende Technologien	2005
Collaborative Research Centers	Magnetismus vom Einzelatom zur Nanostruktur	2006

Source: (DFG, 2006)

In all, the reorganization seems to have been an attempt to do three things at once: centralize Dutch Science funding activities, widening the perspective of science funding from ‘pure’ science to ‘other’ kinds of science including the ‘technical sciences’, and increase the distance between the science funding organizations and the principal Minister for science funding.

As of 1994 a number of 'nano'-labeled investments were made by NWO, STW and FOM through bottom up instruments. In 2000, NWO's Chemical Sciences Division adopts 'molecular nanosciences' as a priority area and one year later, NWO makes 'nanosciences' one of its thematic priority areas. (NWO, 2001a, p. 29 - 30; 2001b). The development of this priority area remained a low priority area, whereas the Dutch government launched a major investment in selected areas among which microtechnology and nanotechnology. This lead to the NanoLink and NanoNed programs, which together received around € 100 M for a period of five years. NWO Divisions later developed a national research agenda for nanotechnology in an attempt to regain some influence on nanotechnology research. In the course of 2007/2008 their attempts merged with NanoNed's attempts to find follow up funding. (Zachariasse, Gielgens et al., 2007)

This story highlights first that bottom up developments did address nanotechnology and that it somewhat later also lead to prioritization by NWO's divisions. Initially, this was a fractioning response by the Chemical Sciences Division, soon followed by an attempt to address the new field in an interdisciplinary way. This was however nullified by the Government's investments, which provoked an institution building response from NWO's divisions.

Norway

As of 1946, several ministries installed and financed a set of research councils and sub councils. By the end of the 1980s, the Norwegian government felt that the system had become too complex and needed reorganization. The preparations took a number of years and as of January 1st, 1993, the existing research councils were merged into one research council called Norges Forskningsråd (NFR - Research Council of Norway). NFR fell under the responsibility of the Kirke-, utdannings- og forskningsdepartementet (KUF - Ministry for Education, Research and Church Affairs) and had six divisions from the start until 2003. These divisions were Culture and Society, Science and Technology, Industry and Energy, Bioproduction and processing, Environment and development, and Medicine and Health. (Arnold, Kuhlmann et al., 2001 p. 34 - 40)

In 2000, KUF commissioned a broad evaluation of NFR, which resulted in, among other things, an internal reorganization of NFR. The new primary division differed fundamentally from the old disciplinary one in that it was a functionally organized, based on NFR's main tasks. As of December 2002, NFR's main divisions were the Division for Science, the Division for Strategic Priorities, and the Division of Innovation (NFR, 2004b). The Division for Science had departments for Social Sciences, Humanities, Physical Sciences and Technology, Biology and Biomedicine, and Clinical Medicine and Public Health (NFR, s.a.).

NFR launched a program called NANOMAT in the first half of 2003. It was the result of a merger of a program on nanotechnology, which was being developed in the former divisions Science and Technology and Industry and Energy, and a researchers' initiative for a materials research program. These researchers had joined forces in the FUNMAT consortium. Initially they had approached NFR for program funding but NFR had denied their request. FUNMAT turned to KUF and convinced it of the importance of investments in materials research[36]. After the Ministry had granted their request it handed the matter over to NFR which merged it with its nanotechnology plan and which also moved the resulting NANOMAT to its new Division of Strategic Priorities. (NFR, 2003a, p. 4; 2003b, p. 4)

Through these developments, nanotechnology with a focus on materials research became a priority of both NFR and the Ministry. Each of these however developed its own interpretation of the field and stressed different aspects. (Ministry of Education and Research, 2005, p. 8; NFR, 2004a, p. 9)

Sweden

During the early 1990s, the Swedish so called 'wage earners' funds' were transformed into a group of research funding foundations. The wage earners' funds were founded in 1984 as investment funds which were to increase employees' influence on companies. The funds were filled with parts of company profits and collectively owned and administered. In 1992 the Swedish government dissolved the funds and trusted the capital to a number of research funding foundations which were established for the occasion around 1994. They were Stiftelsen för kunskaps- och kompetensutveckling (The Knowledge Foundation)[37], Stiftelsen för Strategisk Forskning (SSF - Swedish foundation for Strategic Research) and Stiftelsen för Miljöstrategisk Forskning (The Foundation

[36] Interview with H. Fjellvåg. Interview with J. Taftø.

[37] KKS promotes the use of information technology in society, research at universities and university colleges and the exchange of knowledge between universities, other institutions for higher education, and industrial actors.

for Strategic Environmental Research). These foundations invest their respective capitals' interests to finance their funding and other activities. It makes them relatively independent from the Swedish government because, contrary to most science funding organizations, they do not require annual budgets from the government. On the other hand, the government can appoint chairs of the funds' respective boards. (Granat Thorslund, Sandgren et al., 2004, footnote on p. 9, p. 11)

A bill presented in spring 2000, formally initiated a major restructuring of the other RFOs. As of 1 January 2001 the Council for Planning and coordination of Research, the Council for Research in the Humanities and Social Science, the Medical Research Council, the Natural Sciences Research Council and the Research Council of Engineering Sciences were merged together in the Vetenskapsrådet (VR - Swedish Research Council). (Ministry of Education and Science, 2000)

In addition, a new agency for innovation called VINNOVA was established as a result of a reorganization of the former National Agency for Industrial and Technical Development (NUTEK) (Granat Thorslund et al., 2006, p. 18). Its tasks are wider than to promote research in Sweden. Two other tasks are promoting economic growth and employment through increasing companies' competitiveness and expansion, and secondly, to promote renewal and sustainable growth through support of research and development in selected areas such as transport and communications. Finally, VINNOVA was to stimulate Swedish participation in European and international research and development and exchange of experience with innovation. (Anonymous, s.a.-e; Granat Thorslund et al., 2004, p. 8 - 11); VINNOVA, 2008)

Although in terms of budget VINNOVA and VR are by far the biggest public RFOs and in spite of the fact that five councils were merged into VR, there still is a considerable number of other funding agencies and foundations. Besides the former wage earners' funds and private funds, there also exist:

- Swedish Energy Agency, which was founded in 1998 and falls under responsibility of the Ministry of Sustainable Development
- Swedish National Space Board under responsibility of the Ministry of Industry, Employment and Communication
- The Swedish Council for Working Life and Social Research under responsibility of the Ministry of Health and Social Affairs. The Council was erected in 2001 as a merger of the Swedish Council for Social Research and parts of the Swedish Council for Work Life Research
- Swedish Research Council for Environment, Agricultural Sciences and Spatial planning under responsibility of the Ministry of Sustainable development
- Swedish Environmental Protection Agency under responsibility of the Ministry of Sustainable Development.

- Swedish Agency for International Development Cooperation under responsibility of the Ministry for Foreign Affairs

(Anonymous, s.a.-e; Granat Thorslund et al., 2004, p. 8 - 11))
As of 1997 Swedish RFOs launched several nanotechnology programs[38]. From 1997 until 2002 SSF awarded SEK 26 M to a program called 'Nanoscience Lund' (Anonymous, 2004), which received a two year follow-up funding of SEK 5 M as 'Nano Science, Lund, Extended Graduate School' (SSF, 2005, p. 38). SSF also funded other programs between 1997 and 2004, listed in Table 2 starting on p. 56. All programs were funded through bottom up application processes.

VINNOVA started a program 'Micro and Nanosystems' in its competence area Informations and Communications Technology (Anonymous, 2006). The program ran from 2002 until 2006 and had a budget of around SEK 90 M. A year later VINNOVA started the program BioNanoIT in its competence area Biotechnology. SSF launched its Nano-X program in 2005. It aimed for applied postdoctoral projects that combine nanotechnology with other areas, hence the X. The program runs until 2010 with a budget of SEK 72 M (SSF, 2006, p. 9). Also other programs were carrying the nano-label in their title as of 2005/2006.

In June 2006, VINNOVA granted 15 applications within its VINN Excellence Center program, among which the application Functional Nanoscale Materials (FunMat); High-Impact Surface Engineering Solutions for Industry. The instrument belonged to the competence area Strong Research and Innovation Environments. (VINNOVA, 2006)

Besides these two RFOs, the Kungl. Ingenjörsvetenskapsakademien (IVA - The Royal Swedish Academy of Engineering Sciences) was particularly active, although not in funding. As of 2000/2001, it organized a number of communicative events and activities aimed at coordination and strategy development, in particular of Swedish positioning on nanotechnology within Europe (IVA, 2003, p. 32; 2004, p. 5, 35; 2005, p. 35, 37 - 38, 41; 2006, p. 15).

[38] See also Perez & Sandrgen (2008) for an innovation systems account of the emergence of nanotechnology in Sweden.

Table 2: SSF programs carrying 'nano' in their titles, launched from 1997 to 2004

Area	Programs	Framework Grants	Strategic Research Centres
Chemistry for the Life Sciences		• Designed Nanotubes as Artificial Membrane Channels (2004-2006; SEK 3 M)	
Life Science Technologies	• Nanochemistry (1999 - ...; SEK 40.7 M)		
Biomedical Engineering		• Novel Medical in vivo Monitoring and Targeting of Chemical Microenvironment by Functionalised Nanoparticles (1999-2004; SEK 6.4 M)	
Materials Science and Technology	• Nanoscience Lund (1997-2002; SEK 26 M) • Nano Semi-conductors for Optoelectronics (NANOPTO) (2000-2005; SEK 10.2 M) • Nano Science, Lund, Extended Graduate School (2002-2004; SEK 5 M)	• Multifunctional Photoactive Nanoparticles, Nanoparticle Arrays and Nano-architectures (2003-2007; SEK 14.5 M) • Nanostructures from Self-assembly - in Solution, at Surfaces and as a Synthesis Tool (2003-2007; SEK 14.5 M)	
Micro-systems Technology		• Micro and Nano Pore Arrays for Radiation Detectors and Other Applications (2002-2005; SEK 4 M)	

Table 2 continued

Area	Programs	Framework Grants	Strategic Research Centres
Micro-electronics		• CMOS Integrated Carbon-based Nano-electromechanical Components (2003-2007; SEK 10 M) • Magneto-electronic Nano-device Physics (2003-2007; SEK 15 M) • Wide Bandgap Nanolasers and Transistors for Integration into Silicon Technology (2003-2007; SEK 10 M)	• Strategic Research Centre for Nanodevices and Quantum Computing (NANODEV) (2003-2008; SEK 30 M) • Strategic Research Centre for Nanoscience (2003-2008; SEK 40 M)
	Other modes of support		
Interdisciplinary programs	• Next-NIL (Nano-Imprint Technology) (SEK 4 M) • Quantum Devices and Nanoscience, Gothenburg (1997-2003 ; SEK 21 M)		

Source: (SSF, 2005, p. 26 - 48)

Switzerland

The Swiss research funding organization, similar to the Finnish's, shows a science-technology divide and remained stable during the past two decades. On the science side operates the Schweizerischen Nationalfonds (SNF - Swiss National Science Foundation) which is financed by the Eidgenössisches Departement des Innern (EDI - Federal Department of Home Affairs), and on the technology side the Kommission für Technology und Innovation (KTI - Innovation Promotion Agency), financed by the Eidgenössisches Volkswirtschaftsdepartement (Federal Department of Economic Affairs).

Although this structure remained stable, changes did occur regarding main program funding instruments, operated by SNF, the EDI and the ETH Board. The ETH Board is a body for institutional funding of the two Swiss technical universities and five research institutes. At SNF, the currently existing instruments are managed by SNF but EDI plays a direct role in the selection of proposals. For the program management, SNF installed a fourth division next to its three disciplinary divisions. On this point Switzerland differs from the other countries described in this section.

One of the instruments, the Nationales Forschungsprogramm (NFP - National Research Program) was launched in the 1970s to address societal and political problems. The 36th NFP was a program on Nanosciences, which ran from 1994 until 1999. The second instrument had a predecessor in the 1990s, called Schwerpunktprogramme (SPPs - Priority programs) which focused on particular research areas to make Switzerland attractive for related industries. Half of its programs were managed by SNF and half by the ETH Board. Among the ETH Board's programs was MINAST which ran parallel to NFP 36. When the SPP instrument was abolished, both organizations developed their own successor. SNF and EDI launched the Nationale Forschungsschwerpunkte (NCCRs - National Centres of Competence in Research) which in its first round included an NCCR Nanoscale Science. The ETH Board launched the Technologie Orientierte Programme (TOP - Technology Oriented Programs) with the TOP NANO 21 program. TOP NANO 21 ended in 2004 after which KTI launched the Nanotechnology and microsystems program. Finally, in 2007, the ETH Board and the Schweizerische Universitätskonferenz (SUK - Swiss University Conference) financed the Nano-Tera program which focussed on nano supported microsystems and microtechnology.

United Kingdom

Following the publication of the 1993 White Paper *Realising our potential : A strategy for Science, Engineering and Technology,* the national research funding organization changed dramatically. Before that, as of the beginning of the 1970s, five RFOs were responsible for funding of basic research. The Advisory Board of the Research Councils (ABRC), founded in 1972, advised the Secretary of State for Education and Science on the distribution of budget amongst the research councils. The 1993 White Paper replaced the ABRC with the post of Director General of the Research Councils, established the Council for Science and Technology to advise the Cabinet, replaced the five RFOs by six, and created the Office of Science and Technology, first as part of the Cabinet office, later situated within the Department of Trade and Industry (DTI). (Hackmann, H., 2003, p. 80 - 82, 87)

The five councils existing until 1993 were the Agriculture and Food Research Council, the Economic and Social Research Council, the Medical Research Council (MRC), Natural Environment Research Council, and the Science and Engineering Research Council (SERC). In 1994, the latter was split up. One part merged with the Agriculture and Food Research into the Biotechnology and Biological Sciences Research Council (BBSRC), another became the Particle Physics and Astronomy Research Council, and a third part became the Engineering and Physical Sciences Research Council (EPSRC). (Dresner, 2002, p. 170, 172)

During the following decade other RFOs were founded: the Council for the Central Laboratory of the Research Councils in 1995 and the Arts and Humanities Research Council in 2005 (Anonymous, s.a.-a). In May 2002, an umbrella organization called Research Councils UK was established. Its mission is to optimize the research councils' cooperation, to improve UK research's performance and the research councils' visibility and authority in research funding (Anonymous, s.a.-d). In June 2008, responsibility for the RFOs was transferred to the newly established Department for Innovation, Universities and Skills.

In 1986, the National Physical Laboratory and DTI launched the National Initiative on Nanotechnology which was to raise awareness of nanotechnology's market potential and to encourage co-operation between industry and universities . Two years later DTI launched the LINK[39] Nanotechnology Program in which it invested £ 5.5 M. SERC joined in 1989 through its Nanotechnology Managed Program which fell under responsibility of its Materials Science and Engineering Commission. The last projects were funded in 1995/1996 (Hirst, 1996, p. 1, 24 - 25, 36) and in terms of funding programs, nothing happened until 2002. It is unclear why the RFOs did not continue on the program, but DTI refrained from further investments[40] because industry at that time was not enthusiastic (Science and Technology Committee, 2004, p. 7).

In May 1999, EPSRC organized a so called 'theme day' to review its nanotechnology projects. About a year later a call went out for proposals for Interdisciplinary Research Collaborations (IRCs) in nanotechnology which in 2002 resulted in the launch of an IRC Nanotechnology and an IRC Bionanotechnology. These were funded through a collaborative effort of EPSRC, BBSRC, MRC and the Ministry of Defense which together invested about £ 18 M. (EPSRC, 2002, p. 2)

Recently Research Councils UK launched an initiative to address nanotechnology research, ranging from basic research to final applications, and

[39] LINK is a program, launched in the 1980s, to stimulate cooperation between industry and universities. (anonymous, s.a.-b)

[40] For this it was heavily criticized by the House of Commons Science and Technology Committee in 2004 (Science and Technology Committee, 2004)

including societal and economic implications, and risks. It plans to do so by identifying a series of what it calls 'Grand Challenges' which will be developed by consortia of cooperating UK research council. (Research Councils UK, 2008)

Trends and solutions

The first post World War II decades in most countries saw the introduction of RFOs, and an increase of their numbers under responsibility of multiple sectoral ministries. In the 1980s, technology RFOs were introduced in some countries, but not all. Then followed times of turmoil in the 1990s and early 2000s. They were subject of major reorganizations in Denmark, Finland, the Netherlands, Norway, Sweden and the United Kingdom. France saw its first RFOs and things remained more or less stable in Switzerland and Germany.

In many of the reorganizations, there was a wish to reduce the number of RFOs or divisions in order to more easily accommodate interdisciplinary programs[41]. These wishes originated from ministries or governments, rather than from the RFOs themselves. With the exception of Finland, the attempts to reduce their number were unsuccessful. The reduction was not significant and/or in the years following the reorganizations, new separate RFOs were established. Apparently, the old RFOs and their divisions were too well established in research and government to be reorganized away.

Another similarity between the reorganizations is that attempts were made to bring RFOs under unified control[42], or at least some coordinating power, either by bringing them together under responsibility of one ministry[43] or one umbrella organization[44]. These attempts too originated from ministries and governments rather than from RFOs.

It seems that governments were more willing to direct research through research funding than the RFOs. In cases where the governments were not successful and in countries where governments fully acknowledged the science RFOs' academic freedom, ministries developed parallel funding programs. They involve RFOs in varying degrees in the development and selection of these programs.

The failed attempts towards reduction of RFOs and coordination/centralization did not help the RFOs to address the field of nanotechnology as one field: their response to nanotechnology in many cases was one of fractioning: each RFO or division would develop its own disciplinary cut from nanotechnology and develop it into a program. Typical

[41] Denmark, Norway, Finland, and the United Kingdom
[42] Denmark, the Netherlands, Norway, Sweden, and the United Kingdom
[43] Denmark, the Netherlands, Norway
[44] Denmark and the UK.

illustrations of this are SSF's programs in Sweden and the initial responses of the Dutch NWO divisions.

Some funding programs were developed by RFOs independent of disciplinary divisions. These were the Swiss programs from SNF and the ETH Board, the Norwegian NANOMAT program and the German Collaborative Research Centers. In the Netherlands, Norway and the United Kingdom cooperations between disciplinary RFOs were established as well. In Denmark, the NABIIT committee tried to combine nanotechnology, information technology and biotechnology in one program, thus creating a super-interdisciplinary field.

In Finland and Denmark attempts were made to bridge these countries' science-technology divide and in both countries this resulted in parallel programs on both sides of the divide.

4.2 Framing of nanotechnology

The notions of nanotechnology are discussed here as both acts of boundary work performed by the publishing actors, as well as results of boundary work, performed by others. If RFOs or others establish funding programs for nanotechnology, then the notion of nanotechnology that is used by the program outlines which research projects can be funded[45]. This section provides an exploration of notions of nanotechnology and identifies a number of similarities and differences. These then function as a frame of reference to the notions used for funding programs that are discussed in the case chapters.

The data presented here consists of a mix of around 30 documents that focus on nanotechnology. Many are related to funding programs, but some are of different type, such as governmental policy documents, technological forecasting and assessment reports. Eight out of nine countries are covered, France being the exception because no English report was found. In addition to

[45] It is not assumed that a close connection exists between what programs aim to fund and what the funded researchers actually do. It is also not assumed that researchers will do something completely different, but some 'shirking' may exist. Researchers and program managers see it at as an inevitable part of doing research. After all, exploring the unknown may lead to unforeseen results. From the perspective of governance of research, it is a troubling phenomenon because researchers may also attempt to use funding programs as a means to forward personal research agendas rather than institutionalized agendas.

See Van der Meulen & Shove (2001), Shove (2001) and Shove (2003) for a perspective on the use of funding programs for steering of research. For a perspective from the researchers' point of view, see Dits (1988), Morris (2000, 2004; 2006), Saari & Miettinen (2001), and Van der Most & Van der Meulen (2001).

the countries also European institutions were taken up in the inventory. These were the European Science Foundation, the European Parliament and the European Commission.

The set of documents is not extensive in the sense that it includes all documents about nanotechnology from the nine countries. Some groups of actors were left out, such as non-governmental organizations and companies. Some documents could not be retrieved. Most documents were acquired through web sites and some were web pages. In addition, requests for documents were made at the respective organizations. Unfortunately they were not always acknowledged. The set covers most available documents about funding programs in the nine countries until 2006, and for some countries also thereafter. Hence, this can be an exploration only.

The first observation that can be made is that most documents indeed contain an explicit description of nanotechnology and that a few recent documents do not. A second observation is that the wordings used to describe or define nanotechnology are all different, with the exception of the two reports by Bachmann (1994, 1998). Apparently, most actors after, say, fifteen years still have reason to do develop their own description. One might see the recent exceptions of those who do not as an indication that nanotechnology is becoming so widely known that actors simply assume that their audiences know what nanotechnology is about. Documents about computer science or biotechnology, to take two fields of research which are only one or two decades older than nanotechnology, also do not contain field descriptions anymore.

The descriptions of nanotechnology do show similarities in form. The following types were identified:

- Definitions: easily identifiable blocks of text, usually of a few sentences and often indicated by headings as ‘definition’ or ‘what is nanotechnology’. They provide one essentialist or systematic description of the field.
- General descriptions: longer blocks of text, straightforwardly describing what nanotechnology is about in one way or another. They are similar to definitions, but longer and not explicitly indicated as a definition. Such descriptions may follow after a definition, but may also be presented instead of a definition.
- Historical descriptions: definitions often are accompanied by a historical account and most descriptions include one. One text introduced nanotechnology exclusively as a history of facts and highlights concerning instruments and methods.
- Inventory taking descriptions or reflexive descriptions. Some documents report that there are many definitions on nanotechnology and try to summarize them or distill an essence from the multitude.

- Container descriptions or definitions: these state that nanotechnology can include many things and then try to list these.
- Non-descriptions: texts that do not explicitly introduce the field.

Although the descriptions differ in wording, some closure can be identified on three accounts. Firstly, a core aspect can be identified including a related reasoning describing what nanotechnology is about. Secondly, a set of reoccurring other aspects of nanotechnology can be listed from which different descriptions take different subsets and to which descriptions diverge in content. Thirdly, in terms of content a few basic preferences or strands can identified in the descriptions.

The core aspect that reappears in all descriptions is, of course, the nanoscale. In some documents a layman's or popularized indication of how small this is, is provided: 1 nanometer is 100 000 times smaller than a hair's thickness, or 10 water molecules fit in a nanometer. Pictures may be provided to illustrate the difference between the nano scale and other scales.

The introduction to the nanoscale is often followed by the observation that nature behaves differently on this scale than on a larger scale. For example, it is pointed out that electromagnetic, light refraction and other properties of materials change on that scale, or that it is the scale where laws of quantum mechanics rather than of Newtonian physics rule.

The next step, logically speaking 'after' the observations about the particulars of the nanoscale, the line of reasoning can then continue in two not mutually exclusive directions. One is that the different behavior is not understood very well and thus is an interesting topic for research. The other is that the different behavior provides opportunities for technological innovation. These innovations could in principle be applied in science - new tools - but also in product development. Usually the latter is stressed.

The aspects dealt with above, viz. the scale and the phenomena of the nanoscale, occur in all descriptions of nanotechnology, but both are construed in different ways, like other reoccurring aspects. Here follows a shortlist, starting with these two.

Bandwidth of the nanoscale ; nanotechnology versus microtechnology

In many texts the bandwidth of the nanoscale is delimited, for example from 1 to 100 nanometer (Chehab & Enzing, 1998, p. 3), 0.1 to 100 nanometer (SNF, 2002, p. 24) or "von einigen 10nm bis zu atomaren Abmessungen"[46] (Bachmann, 1998, p. 1).

This delimitation is a frontier of boundary work over the distinction between nanotechnology and micro technology. One indication of that can be found in

[46] 'From a couple of tens of nanometers until the size of atoms' - my translation

the UK. The House of Commons' Science and Technology Committee criticized the Department of Trade and Industry (DTI) for funding nanotechnology with a program that addressed both micro and nanotechnology. “By making no distinction between micro and nanotechnology for the purposes of the MNT [Micro and Nanotechnology Network] Network, the DTI is making no specific commitment to supporting nanotechnology itself.” (Science and Technology Committee, 2004, p. 8). The committee was of the opinion that the distinction should be made, and that microelectronic and mechanical systems should not be part of nanotechnology (p. 8). For the Committee the thrust of nanotechnology originated in the nanoscale: “It is at the nano not the micro scale that the physical and chemical properties of materials change and the scope for revolutionary advances in technology can be realised.” (p. 8).

Almost all[47] documents considered in this thesis delimit nanotechnology at 100 nanometers. The minimum limit differs but usually is 0.1 or 1 nanometer. Funding of nanotechnology and micro technology through one program occurred in Sweden where VINNOVA operated the Micro and Nanosystems program from around 2002 to 2006, and in Switzerland through the 1996 - 1999 MINAST program.

Nanoscience versus nanotechnology

A distinction between nanoscience and nanotechnology occurs in the documents, although not all documents make an explicit distinction. Some documents focus on either nanotechnology or nanoscience and leave the other out. Some documents locate both science and technology under the label 'nanotechnology' : “Nanotechnology refers to science and technology operating at ...” (Anonymous, s.a.-c) However, in most cases that make a distinction, the argument basically is that nanoscience studies phenomena at the nanoscale, whereas nanotechnology tries to develop applications that exploit phenomena of the nanoscale. For example: nanoscience is presented as the "basic scientific foundation of nanotechnology" (SNF, 2002, p. 24), or "Nanotechnology, ..., can be considered to include applied nanoscience together with exploitation." (Academy of Finland, 2005b, p. 35). Occasionally, texts evade the distinction by referring to the 'nanoscale' or the 'nanometer'.

The issue of distinguishing nanoscience from nanotechnology is related to the science-technology divide. RFOs on the technology side tend to stress the technology part and make that the focus of nanotechnology. RFOs on the science side tend to stress the study of phenomena and refer to nanoscience rather than nanotechnology.

This thesis uses the word 'nanotechnology' to refer to both nanoscience and nanotechnology, unless a particular actor's view on the distinction is discussed.

[47] The exceptions being Tekes (2000, p. 3), which used a range of "~1-1000nm".

Nanotechnology's interdisciplinary character
Most documents refer to the interdisciplinary character of nanotechnology. Here three angles on the issue can be distinguished. Firstly, nanotechnology is explained to be a field in which a number of existing disciplines, such as physics, chemistry, biotechnology, materials science and microelectronics, merge. These could be labeled the mother disciplines. Often they are mentioned but in those cases not much attention is paid to the list.

The second angle is the subdivision of nanotechnology internally, say the child-disciplines. Arguably, the child disciplines can be a completely new set of fields because nanotechnology is a new field. In the documents, the child disciplines are nanoscale versions of mother disciplines, such as nanophysics, nanomaterials and bionano. A fourth subfield is nanometrology: apparently, measuring and characterizing materials and behavior at the nanoscale is perceived as a subfield in itself.

The third angle is that some documents, in particular those related to a funding program, focus on one of these subfields which then also is the focus of the funding program.

Top down - bottom up
'Top down' nanotechnology refers to lithographic technology that etches structures with increasingly smaller detail in materials. In due time, the technology is able to produce details in the range of 45 to 65 nanometers[48]. Lithography is used and further developed for the production of integrated circuits. 'Bottom up' nanotechnology refers to technologies that are being developed to produce ever bigger molecules from smaller molecules or atoms. The machines that are necessary to produce structures in both cases can be complicated, expensive and may be demanding in terms of operating conditions, which makes their deployment more expensive. Costs are an issue that is addressed, although hardly ever stressed in the documents.

Spatial dimensions for the nanoscale
Another observation is that in some documents, besides nanotechnology's bandwidth, also the number of spatial dimensions to which the bandwidth applies is specified. Zachariasse (2003) specifies that one or more dimensions should be in the bandwidth of 0.1 to 100 nanometer. If one dimension suffices than nanotechnology would include research on films. If two dimensions were the minimum than films research would not be included, but nanotubes would. If the nanoscale would have to apply to all three dimensions, then nanotubes longer than 100 nanometer would be out of scope but some proteins would be included.

[48] See www.asml.nl (2-3-2007)

Concluding

A 'core' notion of nanotechnology can be distinguished. It starts with the nanoscale, points out that unknown phenomena occur at that scale, and continues that this requires basic research to understand them and/or that the phenomena provide opportunities for innovation. In addition to this core a number of often mentioned aspects can be identified: the bandwidth of the nanoscale, nanotechnology vs microtechnology, nanoscience versus nanotechnology, nanotechnology's interdisciplinary character, top-down versus bottom-up nanotechnology, and the number of spatial dimensions.

5 Switzerland: bottom-up, top-down, but business-as-usual

5.1 Introduction

Switzerland is the country where in 1981, the scanning tunneling microscope, the single most important tool that opened up the field of nanotechnology was invented. Five years later, H. Rohrer and G. Binnig received a Nobel prize for this invention. Switzerland was identified in some of the first European technology radar reports that addressed nanotechnology (Bachmann, 1994, p. 123; Hirst, 1996, p. 23 - 24).

After the UK, Switzerland was the second European country which launched a funding program carrying the term 'nano' in its title[49]. Moreover, it is one of the few which continued to launch such programs even before the United States' National Nano Initiative. By the end of 2008, various Swiss actors had launched six programs in all.

How did this develop? Well, part of the answer is obvious. There were the people who invented the scanning tunneling microscope, which was important enough to award them a Nobel prize. Obviously, they and their colleagues wanted to keep working on and with this new tool and they successfully applied for program funding. Once they got their research up and running, they wanted to continue on it, so they applied again when the first program was about to end. Again, they were successful and in the course of time, different groups in nanotechnology research developed in Switzerland. This however, summarizes only part of the story.

The more interesting part concerns the role of the Swiss national science RFO, the Schweizerischen Nationalfund (SNF - Swiss National Science Foundation). When it comes to the ability to identify new fields and the mechanisms that allow it to respond to developments, SNF shows that it can do without and still be an RFO in a country that responded quickly to the rise of nanotechnology. How can this be? SNF plays a role as a supporting organization for program funding and it champions the peer review processes that guard scientific quality. Apart from that, it doesn't actively involve itself in identifying and selecting priorities. This is due to the strong position that Swiss political bodies

[49] The UK's National Physical Laboratory and the Department of Trade and Industry launched the National Initiative on Nanotechnology in 1986. (Hirst, 1996, p. 24)

have in the decisions about research priorities, and that researchers have in proposing such priorities.

Switzerland dealt in its own way with the pressure that has been building up in the course of the last, say, four decades and which requires governments, researchers and research funding organizations to justify the public investments in research in increasingly more direct ways. Switzerland introduced the Nationale Forschungsprogramme (NFP - National Research Programs) in the mid 1970s to address pressing societal problems. The implementation of this program instrument introduced a particular division of resources and labor, which is particular compared to programs at other science RFOs. The means were provided by the Federal Council[50], the ideas for programs by researchers, the political selection by the Federal Council, and the feasibility evaluation by SNF. This program funding instrument produced NFP Nanosciences as its 36th program. It is one of the first nano-labeled funding programs in Switzerland with research projects starting in 1996.

A few years earlier, the Swiss Federal Council launched a new program instrument called Schwerpunktprogramme (SPP - priority programs), which aimed for restructuring the Swiss research landscape through establishing new research centers. With the SPPs, the Federal Council wanted to make Switzerland an attractive partner for industry in particular fields such as high power electronics, optics and environmental research. In 1996, two new SPPs were launched in a second round, one of which was the Mikro- und Nano-Systemtechnik program (MINAST - Micro and Nano systems technology).

The Federal Council assigned half of the SPPs to SNF and the other half, including MINAST, to the ETH Board. The ETH Board was established in 1993 as a successor of a body through which the Federal Council governed two technical universities and four research institutes, together called ETH Domain. With their launch, the ETH Board and the ETH Domain received more autonomy than their predecessors had before them. The ETH Board changed from an administrative body into a strategic body of governance for the ETH Domain.

When the Federal Council abolished the SPP instrument after eight years, the ETH Board as well as SNF launched a successor instrument. The ETH Board launched the Technologie Orientiertes Program (TOP - Technology Oriented Program). The TOP instrument was a continuation of the SPPs in the sense that it tried to combine basic research with a focus on technology development and with commercial application. It was a project funding instrument which did not aim to establish new research centers. SNF together with the Federal Council launched an instrument that aimed less for technology development and economic application but continued the SPP's attempts to establish new research centers. Hence, the instrument was named National Centres of Competence in Research (NCCR).

[50] The Federal Council is the Swiss federal government.

Through both new instruments, programs on nanotechnology were launched: TOP NANO 21 and the NCCR Nanoscale Science. To arrive at their selection of programs, SNF and the Federal Council used a bottom up approach and kept the division of resources and labor in place that was used for the NFPs. That is, they depended on Swiss researchers to develop program proposals, involved SNF to organize scientific quality evaluation, and included the Federal Council for political selection. The ETH Board used a selection procedure which did involve researchers to develop ideas, but otherwise remained an internal affair in line with the Board's strategic role.

This summary spans up the story of this chapter. Considering this thesis's main question, this chapter gives an example of how an RFO deals with the challenge that new emerging fields present while not involving itself in or dedicating itself to the new fields. A structure and a procedure are in place which deal with new fields, but which leave detection of the new fields, developing proposals to address new fields and the selection of these proposals to researchers and governmental actors outside the RFO. SNF limits itself to a supporting role by providing an organizational structure and administrative support. Through such a solution, SNF operates with a distribution of resource dependencies which is different from RFOs discussed in other chapters.

The ETH Board presents a different type of response, similar to how strategic or mission oriented RFOs in other countries operate. The Board made a dedicated choice for, in this case, the field of nanotechnology. Compared to other programs described in this thesis, TOP NANO 21's program design stands out because it tries to combine basic research, technology development and commercial application at both program and project level.

5.2 The Swiss research funding constellation

When RFOs are considered, the Swiss national organizational structure shows a science-technology divide as outlined in Section 2.2. Basically, there is one organization for funding of technology development which falls under the responsibility of the Federal Department of Economic Affairs and one for science funding under the responsibility of the Federal Department of Home Affairs. In addition, the two organizations use different operational procedures and have different sets of resource dependencies.

Besides the science-technology divide, the Swiss research funding structure also shows a clear division of labor between SNF and the Federal Council. When in 1952 SNF was established, it was not allowed to fund research by means of program funding. In the course of time, SNF did become involved in programmatic funding instruments. In 1975, the Swiss government introduced the Nationale Forschungsprogramme (NFP - National Research Programs). In the selection procedures of this instrument, SNF's role of evaluator of scientific quality was separated from the Government's role of identifying program priorities. This division to a large extent structured how SNF dealt with the field of nanotechnology, or put differently, how SNF played only a supporting role in the prioritization of nanotechnology.

Outline of research funding and nanotechnology related industries

A division of funding between the Federal Council and the cantons dominates the Swiss research funding structure. Whereas the cantons finance the universities, the Federal Council finances the technical universities and a small number of research institutes currently known as the ETH Domain. In addition, the Federal Council finances Switzerland's national scientific and technology RFOs, viz. SNF and KTI. Developments leading to this situation started in the middle of the 19th century and reached the current situation in the 1970s.

Compared to universities in other countries, Swiss universities and to a greater extent the ETH Domain are relatively well to do in terms of facilities and equipment. Universities can apply for extra budget for equipment and facilities at the Federal Council. One condition for such an application is that the cantons co-finance the application.

In the 1980s and 1990s, SNF funded equipment on fifty-fifty basis.[51] SNF operates the R'Equip program for subsidies on equipment and facility funding. If finances up to 50% of equipment and facility costs which cannot be considered part of regular basic equipment. The minimum acquisition costs should be CHF 100 000 (Nationale Forschungsrat, 2005; SNF, 2009a).

The Swiss Federal Council has no department for education because the cantons have the authority over that sector. Those issues concerning education and research that the federal authorities deal with are located within the Eidgenössiche Department des Innern (EDI - the Federal Department of Home Affairs). Within EDI, different offices have been in place to handle federal research policy, SNF, NFPs and ETH affairs. As of 2005 the State Secretariat for Education and Research handles them all[52].

[51] Interview with K. Höhener. Interview with C. Schönenberger. Interview with G. Wagnière and P. Burkhard.

[52] Interview with K. Eggenberger.

The Swiss industries related to nanotechnology can be found in pharmacy and high precision instruments and miniaturization, the latter building on the Swiss watch making tradition. There are a number of companies interested in surface science and electronics. Switzerland has, among other companies, an IBM research laboratory and a company called Meyer Burger, which produces machines for the production of computer chips.[53]

A division of labor in research priority selection between SNF and the Federal Council

When SNF was founded in 1952, its mandate was limited to funding of individual projects in order to preserve the cantonal and university autonomy. In the course of the next two decades, SNF's tasks were expanded through incorporation of the Swiss Atomic Energy Commission in 1957, funding of research institutes in 1965 and funding of research in social and preventive medicine in 1969. (Lepori, 2006, p. 214) In the second half of the 1960s, the universities were under pressure because of increasing student numbers. Cantons fell short of money to finance the universities and asked the Federal Council for additional funding which it provided as of 1967 (Hill & Rieser, 1983, p. 54). This partly eroded the separation of university funding and funding of research institutes. However, the cantons remained principally against federal intervention in higher education (Lepori, 2006, p. 214).

In the 1970s, politicians began to criticize SNF's restricted role in research funding and it was suggested that an additional funding organization was established for policy or economic interests driven research. The Federal Council accepted this criticism and introduced the instrument of Nationales Forschungsprogramme (NFP - National Research Program) in 1975. SNF received the task of managing the NFPs (Hill & Rieser, 1983, p. 293 - 364; Lepori, 2006, p. 214).

The Federal Council and the Parliament decided that at most 12% of SNF's total budget would be labeled for the NFPs. The NFPs' main aim was to contribute to the solution of problems of national interest. However, as the Federal Council expressed in its White Paper on the support of scientific research 1984-1987[54], this should not lead to too high expectations. According to the Federal Council, the NFPs would not actually solve problems, but provide basic knowledge to support policy decisions, generate new knowledge and

[53] Interview with G. Wagnière and P. Burkhard.

[54] The Swiss 1983 Federal Research Law (Bundesversammlung der Schweizerischen Eidgenossenschaft, 1983 - 2004) introduced the system of multi annual White Papers. Each White Paper would establish the outlines of the Swiss federal research policies and maximum expenditures for the multi annual period. Ever since, such White Papers were presented to the Swiss Federal Parliament, each time covering a four year period.

convey this in an intelligible way to relevant actors in the field. (Schweizerischen Bundesrat, 1983, p. 1432, 1456)

Calls for proposals for NFPs are sent out by the Staatsekretariat für Bildung und Forschung (SBF[55] - State Secretariat for Education and Research). Calls do not have a predefined list of priority themes and allow all Swiss citizens to send in proposals. Proposals are sent to SBF which makes a selection while involving all other Ministries and the Wissenschaftsrat[56] (Swiss Science Council) in this process. The resulting list of up to 12 eligible proposals is then sent to SNF which performs a feasibility study for each of the proposals. It checks whether there is enough research potential in Switzerland for the programs. Only in a few cases, SNF advises negatively[57]. Occasionally, SNF advises to change particular points in programs or advises to use a different funding instrument. After SNF's feasibility study, the Federal Council takes the final decision on NFPs. The management of the NFPs is then handed over to SNF.[58]

NFPs receive between CHF 5 M and 20 M. By the end of 2008, more than 60 NFPs had been launched, of which about 10 were ongoing. Within the remits of the respective NFPs, open calls for projects and peer review procedures were the general practice. At SNF, a specific division for Orientierte Forschung (Priority Funding), also known as Division IV, is responsible for managing the NFPs. The division operates next to three disciplinary divisions for social sciences, natural and exact sciences, and biology and medicine, thus separating prioritized research from open project funding.

The science-technology divide in Switzerland

SNF is a typical science RFO. It has many, if not all, characteristics thereof: it funds public scientific research, it receives funding from a federal department responsible for research and education and it uses a peer review system for application evaluation. Because SNF only administers the funding programs, but does not develop them, resource dependencies are limited to budget from the Federal Department of Home Affairs and the accompanying legitimation that the Federal Department also provides to SNF to perform the task. For

[55] SBF is located within the Federal Department of Home Affairs and is the responsible department for general and higher education, research and space research. SBF was created in 2005 as merger of the Bundesambt für Bildung und Wissenschaft (Federal Office for Education and Science), the Swiss Space Office and the Office of the Secretary of State of Education and Research.

[56] The Swiss Science Council, currently known as the Schweizerischer Wissenschafts- und Technologierat, the Swiss Science and Technology Council. The Council is an advisory council to the Federal Council in all matters concerning science and technology. See SWTR (2008) for more information.

[57] One out of five in the 2001/2002 round, one out of four in the 2002/2003 round and none out of six in the 2006/2007 round. Interview with K. Eggenberger.

[58] Interview with S. Bachmann. Interview with K. Eggenberger. Interview with G. Wagnière and P. Burkhard.

further program development after a proposals are granted and for steering the programs, SNF depends on researchers to participate in program steering committees, review of project proposals and program evaluation.

On the technology side of the science-technology divide, Switzerland operates the Kommission für Technologie und Innovation (KTI - Commission for Technology and Innovation). Compared to other countries discussed in this thesis, KTI is the oldest in its kind[59]. In 1944, it was established as the Kommission zur Förderung der wissenschaftlichen Forschung (KWF[60]). Its aim was to support research that lead directly to new products and would thus increase the need for labor in industrial production settings. After being located in the Department for Defense, it moved to the Department of Economic Affairs in 1946, where it remained ever since. (Braun, Griessen et al., 2007, p. 33; Fleury & Joye, 2002, p. 64 - 97)

In terms of available budget, KWF remained a relatively small organization. Ruling policy saw finance of research leading to new products as a matter for private enterprises. If funding were made available to industry, then that would be limited to those companies in clear need of support, that is, medium and small sized enterprise. KWF would fund projects in which enterprises and public research institutions would cooperate and would only fund the second type. As of the 1970s, in addition to open projects, KWF slowly developed programmatic funding, but the overall budget remained relatively small. Typically, in 2007, it was about one fifth of SNF's budget. (Braun et al., 2007, p. 33)

In 1996, KWF was renamed into Kommission für Technologie und Innovation. Around 2000, the commission had 27 members. 60 Percent of its members had a background in private enterprise and around 40 percent in higher education related research. The latter group had experience in private enterprise as well. Next to these two groups, there were representatives from federal departments with which KTI cooperates. (Grunt & Reuter, 2001, p. 11).

Around 2000, KTI's application procedures had no calls for applications. Applicants could send in proposals whenever they want to. Their applications were reviewed by two committee members and, if needed, by additional external experts. Applications required at least 50 percent support in the shape of personnel costs from private enterprise. After being accepted by KTI, the Federal Department of Economic Affairs took the final funding decision. Between 1986 and 2000, ETH organizations and in particular the two technical universities acquired close to three quarters of all KWF/KTI funded projects (Grunt & Reuter, 2001, p. 11 - 15, 29, 40 - 45) In short, around 2000[61], KTI basically shows a number of important family characteristics of a technology

[59] In other countries such initiatives had led to the establishment of research institutes for technological research. Examples are TNO in the Netherlands (1932) and the Fraunhofer Gesellschaft in Germany (1949).

[60] Unfortunately, I found no official translation, but I would freely translate to 'Committee for the promotion of scientific research'.

RFO: it funds technology development, requires academic applicants to cooperate with private enterprise, it is financed by a Federal Department responsible for economic affairs, and it primarily depends on internal experts for application reviews.

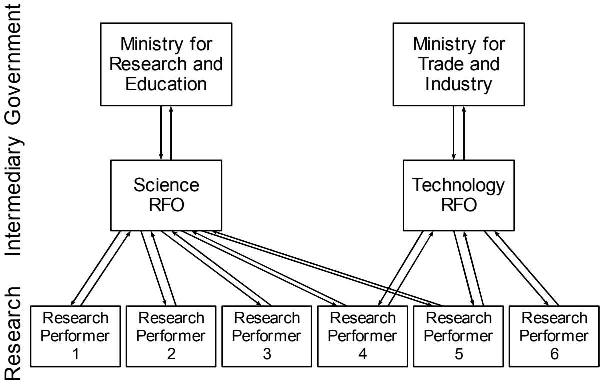

Diagram 3: Schematic science-technology divide

The overall science-technology divide involving SNF and the Federal Department of Home Affairs, and KTI and the Federal Department of Economic Affairs comes close to the schematic science-technology divide as depicted in Diagram 3.

5.3 NFP 36 Nanowissenschaften

Most historical accounts of nanotechnology's development, mention the invention of the so called scanning tunneling microscopes in 1981 as one of the milestones, if not the single invention that opened up the field of nanotechnology. Scanning tunneling microscopes (STMs) generate images of solid surfaces showing individual atoms that constitute the surface and atoms placed on top of the surface. Inventors H. Rohrer and G. Binnig received the 1986 Nobel prize in physics for their achievement.

Rohrer successfully applied for an NFP on physics and chemistry of surfaces. The program, NFP number 24, was developed in the course of 1987 and 1988 and its projects ran during the first half of the 1990s. Towards the end of the program, Rohrer and his Swiss colleagues wanted a follow up program. Guided by Rohrer, G. Wagnière applied for an NFP on nanosciences. The application was successful, partly because Rohrer, described as a good communicator and locomotive for nanotechnology, was able to convince politicians of the

[61] The last few years, KTI has been going through a transformation into a agency with the autonomy to make funding decisions itself. It was renamed Förderagentur für Innovation KTI. (2008; Schweizerischen Bundesrat, 2009)

importance of nanosciences. (SNF, 1988)[62] In December 1993, the Federal Council decided to award Wagnière's application a CHF 15 M credit. It was the 36th program and hereafter is referred to as NFP 36.

NFP 36

This subsection describes NFP 36 in detail to provide an illustration of bottom-up development of an NFP. In addition, it shows how, in these early years of nanotechnology, actors approached the challenges posed by the emerging field as set out in the Introduction, viz. dealing with a field while it is under construction, dealing with its interdisciplinary character and its demands for equipment and facilities, and its answers to societal demand for a close relation between research and industry.

Definition of nanotechnology
NFP 36 did not use a formal definition of nanotechnology although its implementation plan step by step makes clear what the program is about. On the first page, its research area is described as "Die physikalische, chemische und biologische Untersuchung von Strukturen un Prozessen auf der Nanometerskala (10-9 Meter) ..." (SNF, 1994, p. 1) The plan points out that the possibility to experiment with and handle individual atoms and molecules makes the field interesting :

> " Die Perspektive, mit Einzelatomen und Einzelmolekülen experimentieren und hantieren zu können, eröffnet für die Materialwissenschaften, Analytik und Werkstofftechnologie dementsprechend eine neue Epoche." (p. 2, stress in original)

The individual localizability of atoms and molecules was an important aspect because the program was triggered by new research methods that had become possible through the use of STMs and other scanning microscopes. NFP 36's expert committee adhered to his aspect and rejected one third of the initial project proposals because they did not comply with this focus.[63] The program was not tightly formulated in terms of the number of atoms or molecules that the research projects should study. Also, systems consisting of small number of atoms or molecules could be the focus of funded research projects.

Program objectives and subdivision of nanotechnology
The program aimed for a interdisciplinary approach, in the sense that it not only targeted the physics of the nanoscale but also the chemistry and biology (SNF, 1994, p. 1). It used a subdivision of nanotechnology which followed the

[62] Interview with G. Wagnière and P. Burkhard.
[63] Interview with G. Wagnière and P. Burkhard.

lines of existing disciplines: nano-electronics, nano-mechanics, nano-biophysics, nano-chemistry, nano-optics, and nano-tools and methods (SNF, 1994, p. 7-13; Trueb, 2000). It was felt that one cannot immediately start on a new field, and that to define it in detail one has to start from the existing disciplines. It was also felt that projects that were not based in existing fields, would run the risk of being ill defined and of producing non-reproducible results or no results at all.[64] However, the idea behind the program was that things would not remain in the different subfields, and to prepare them for a more interdisciplinary level revolving around the use of the STMs.[65]

The program, which was titled Nanosciences, was explicitly aiming for funding of basic research, arguing that the industrial applications of nanotechnology were not yet fully foreseeable. The implementation plan called for the development of perspectives on new technologies for applications and production methods, but this remained an open suggestion. Project applications aiming for development of end products were referred to the MINAST program for nano and micro systems technology, and to the program on optics, both managed by the ETH Board. (SNF, 1994, p. 1, 3).

Legitimization

The reasons mentioned for initiating the program primarily focused on the development of the STM and other similar tools which allowed new research methods. This opened up a new field and as mentioned above, the program claimed the start of a new era for some scientific disciplines. So, an important legitimization of the program consisted of considerations of scientific development.

The implementation plan in addition predicted new industrial developments based on nanoscience. It was pointed out that nanotechnology opened unexpected new perspectives on miniaturization. Higher efficiency became possible which could also be economically interesting. (SNF, 1994, p. 1, 2, 5)

Switzerland's head start in the field was another important motivation for the program. Its implementation plan pointed out that the STM, the atomic force microscope and the scanning near field optical microscope were invented in Switzerland. This gave Switzerland a head start on other nations which presented an opportunity the country should grasp, the plan suggested. In addition, it pointed out that although Switzerland had a strong tradition in micro mechanics, it had only hesitatingly involved itself in miniaturization in micro electronics. Nanoscience offered an opportunity to take the lead again in a field that other nations had started to develop. (SNF, 1994, p. 2)

[64] Interview with G. Wagnière and P. Burkhard.
[65] Interview with G. Wagnière and P. Burkhard.

Organization of the program
Like all NFPs, NFP 36 had an expert committee, a scientific program manager and an SNF official/program administrator. Next to that H. Rohrer acted as consultant to the program. The expert committee and the scientific program manager deserve some closer attention because that provides insight in SNF's dependencies on researchers' volunteer work and political support.

The expert committee was recruited after the Federal Council had approved the program application. Identifying candidates was not a difficult task for Wagnière and SNF. Switzerland is a small country, so they had good oversight. They tried to find representatives of different disciplines, such as physics, chemistry and biology, to cover all disciplines involved in nanotechnology. The field's interdisciplinary character also stimulated the candidates' interest, which was helpful because not everybody was willing to make his/her time available. Other important criteria for selecting candidates involved their university or institute, and their language area. Wagnière and SNF felt that a certain distribution is necessary for political support. Politicians were assumed to skim the lists to check for a more or less fair distribution.[66]

Between June 1994 and the end of that year, the expert committee met six to eight times to discuss text proposals for the implementation plan which were written by Wagnière and Rohrer. It also recruited the scientific manager, and later reviewed the project proposals. H.E. Hintermann was selected as candidate program manager because of his experience as expert committee member for NFP 24. He would visit all applicants and their laboratories and helped them with their applications.[67]

The program's application procedure involved two steps. Firstly, a call for five page sketch proposals went out in January 1995. Sketch proposals were to discuss project goals, scientific questions, research methods, potential use of expected results, the name of the project leader, cooperation with other researchers in Switzerland and abroad, and an indication of costs and planning. The call closed in March of the same year and resulted in about 100 sketches.

The expert committee reviewed the sketch proposals during a two day session. As mentioned above, the committee rejected about one third because they did not comply to the criterion of individual localizability of atoms/molecules. Some of them were of good quality and these were referred to another SNF division. SNF invited those applicants whose sketch proposals passed the evaluation to write full proposals.

The full proposals were also evaluated by the expert committee. The committee members distributed the proposals amongst themselves to write short evaluations. It turned out that not all qualified proposals could be financed with the available budget. The committee then tried to fund as many

[66] Interview with G. Wagnière and P. Burkhard.
[67] Interview with G. Wagnière and P. Burkhard.

high quality projects as possible, in particular the most interesting proposals or those from the most talented applicants.[68]

As one criterion for funding considered the proposal's interdisciplinary character, some proposals were rejected because they lacked interdisciplinary cooperation. Hintermann played a facilitating role. Through his site visits, he helped researchers building contacts with others. Another means of promoting nanotechnology's interdisciplinary character were the program's common meetings on for example the architecture of tips for STMs, or on other nano-metric methods such as scanning force microscopy.[69]

The program had a budget of CHF 15 M, which is a normal amount for an NFP. To fund research, NFP 36 exclusively used project funding based on bottom up proposals and open competition. In all, it funded around 45 projects. (SNF, 2009b) It did not have a funding instrument for facility or equipment funding. Through its research projects, it did fund some equipment, such as STMs. In the 1990s, these costed about CHF 250 000. When the program committee tried to reduce project costs, one way was to require groups to share such equipment.[70]

Most of the NFP 36 projects started in 1996 and finished around 1999. The program officially ended in June 2000. By that time, the MINAST program on micro and nano systems technology had finished and two successors of MINAST had been launched or were being developed.

5.4 The MINAST program

In January 1991, the Swiss Federal Council presented its research policy White Paper covering the period 1992 to 1995 to the Federal Assembly. The Council proposed the introduction of a new national program funding instrument called Schwerpunktprogramme (SPP), priority programs. Braun & Benninghoff (2003, p. 1854), following the Schweizerischer Wissenschaftsrat (1994), report that this proposal resulted from an initiative of the Schweizerische Schulrat, in collaboration with the Schweizerische Universitätskonferenz (SUK - Swiss University Conference), and was developed under pressure from the Swiss economic situation.

The latter part is also the argument that the Federal Council put forward. One year earlier, it had noted that Switzerland had become less and less

[68] Interview with G. Wagnière and P. Burkhard.
[69] Interview with G. Wagnière and P. Burkhard.
[70] Interview with G. Wagnière and P. Burkhard.

attractive as a base for technology development and industry. The Council also referred to an analysis from OECD experts about the Swiss research and technology policies. Furthermore, the Federal Council observed that other countries, worldwide and in particular European Union countries, were stepping up their efforts in a number of technological fields through funding programs for strategic research centers, foresight studies and program-based research funding (Schweizerischen Bundesrat, 1991, p. 613, 622 - 623)[71]. To deal with these trends[72], the Federal Council proposed a set of six SPPs in the fields of high power electronics, optics, environmental research, materials research, biotechnology and computer science. In case of four themes, the White Paper refers to proposals that were submitted by researchers from the ETH Domain, which suggests a bottom up development, similar to the NFPs. The theme of materials research was brought forward by industry and the theme of computer science was identified by SUK. (p. 613)

SPPs were designed to differ from NFPs in that the SPPs budget would be about ten times higher and they would last about twice as long. The Federal Council expected a structural, long term and deep impact on Swiss research which would make up for the Swiss backlog areas. (Schweizerischen Bundesrat, 1991, p. 613 - 614) The goal was to build capacity, research institutes and other structures for the new fields[73]. Two SPPs were meant to launch a new research institute and the White Paper stressed that these programs would require funding also after the year 2000 (p. 657 - 658). In its four year budget, the Federal Council added about CHF 360 M to the research policy account to fund the SPPs. This was 17% of the total four year budget[74]. (p. 607, 625, 671). Without further explanation, the Federal Council proposed to locate management of three SPPs at SNF and the other three at the ETH Board (p. 659).

In spite of the Federal Council's ambitious funding scheme, the SPPs received 40% less than budgeted as a result of the federation's general cut back measures. In its 1994 White Paper for the period 1996-1999, the Federal Council continued the SPP instrument, but compared to the previous White Paper, it placed more emphasis on the aspect of technology transfer (Schweizerischen Bundesrat, 1995b, p. 920). The Council proposed to stop two programs and launch two others, one in social sciences and one on micro and nanotechnology, called Mikro- und Nano-Systemtechnik (MINAST). (Schweizerischen Bundesrat, 1995b, p. 927 - 928, 935 - 937)

MINAST was assigned to the ETH Board and the Federal Council proposed to invest CHF 120 M in MINAST, which was about twice as much as the other SPPs received on average and also more than twice as much as the program

[71] Interview with S. Bachmann.
[72] Two SPPs were proposed for different reasons, not described here.
[73] Interview with S. Bachmann.
[74] This budget did not include the ETHs and related institutes

eventually received. Industrial partners in the projects invested about CHF 60 M. (ETH Rat, 1998, p. 3364; Schweizerischen Bundesrat, 1995b, p. 937)

MINAST[75]

The draft proposal of the MINAST program was primarily focused on microtechnology. It provided a description of microsystems and then added

> " It can be expected that the current scale of established microtechnology will be extended in to the range of nanometer dimensions (1nm=10 Å = 10^{-6} mm). the nanometer range includes dimensions of less than 100 nm. This is the domain of atoms, molecules and ensembles thereof.
>
> Methods and techniques in nanotechnology have to take the smallness, extreme conditions and large numbers of compounds into account." (MINAST, 1994, p. 5)

In the remainder of the proposal, nanotechnology also received little attention and was positioned as an application domain for microtechnology as a quote about the program's objects illustrates (see below).

Placing microsystems in Switzerland's "tradition in the research, the development and the production of miniaturised products, microsystems technology and its application in the nanometer domain" (MINAST, 1994, p. 5) MINAST's main objectives were, "to achieve and maintain academic and industrial leadership in the field of microsystems technology and its application in micro- and nano-systems" (p. 5), to promote technology transfer, develop skills and capacity for the emerging microsystems industry, support the industry in view of future requirements for increasingly more complex and multi-functional products, stimulate companies and SMEs to develop microsystems. (MINAST, 1994, p. 5)

The program funded projects only. As projects had already been defined together with the program proposal, there were no calls for projects (MINAST, 1994). All projects cooperated with at least one, but in most cases two or more industrial partners (MINAST, 1999) who also were required to invest in the projects. (ETH Rat, 1998, p. 3364) The program did not have a particular funding instrument for equipment and facilities but one proposed project involved an upgrade of equipment at the Sensors , Actuators and Microsystems Laboratory at the Institute of Microtechnology of the University of Neuchâtel (MINAST, 1994 proposal 1.01 p. 1). This involved a deep reactive ion etcher

[75] Most information in this subsection is presented on provisional basis because the most important source of information available to me is a draft program proposal (MINAST, 1994) from October 1994.

which was used in all projects of one of MINAST's micro technology modules (MINAST, 1999, p. 12).

MINAST was eventually[76] organized in seven modules which were developed and lead by seven different researchers. The program had a director, a deputy director, a program coordinator and a program management team. The team was chaired by the director and consisted of 5 representatives from industry and 5 university professors or directors of research institutes. This team had the mandate to take decisions on all aspects of the program, including the (dis)continuation of projects and launch of new projects. (MINAST, 1994, p. 13)

Besides the management team also a body of representatives from the Federal Council, research units and industry acted as governing board, provided advice and represented the program's interests to the ETH Board and other authorities. Finally, a group of experts was envisaged to be set up by the ETH Board and to develop implementation plans for projects[77]. (MINAST, 1994, p. 13)

MINAST ended around the year 2000. It was not continued in another round, because the SPP instrument which funded MINAST was discontinued. Actors had their doubts about it.

Discontinuing the SPPs

In November 1998, the Federal Council presented its White Paper on education, science and technology for the years 2000 until 2003 to the Federal Assembly. The Council argued for replacing the SPPs with a new instrument called Nationale Forschungsschwerpunkte or National Centres of Competence in Research (NCCRs[78]). Its main argument was that it wanted a better system of programmatic funding instruments through a clearer conceptual difference between the NFPs and the SPPs. It wanted NFPs to be more focussed on science based problem solving, and the SPPs more on concentration of research capacity and a more efficient division of research labor. (Schweizerischen Bundesrat, 1999, p. 353 - 354)[79] SNF agreed with the Federal Council[80].

[76] The draft proposal listed 12 modules, the Federal Council's research White Paper mentioned the number of 10 modules and MINAST's final conference report listed 7. (MINAST, 1994, 1999; Schweizerischen Bundesrat, 1995b, p. 354)

[77] The experts also "handles the public calls for tender and evaluates the submitted research projects" (MINAST, 1994, p. 13). This is difficult to understand because projects within the modules were already described in detail in the same proposal.

[78] The official abbreviation for Nationale Forschungsschwerpunkte is NFS. However, to avoid confusion between NFS and SNF, I will use NCCR.

[79] Interview with G. Wagnière and P. Burkhard.

[80] Interview with G. Wagnière and P. Burkhard.

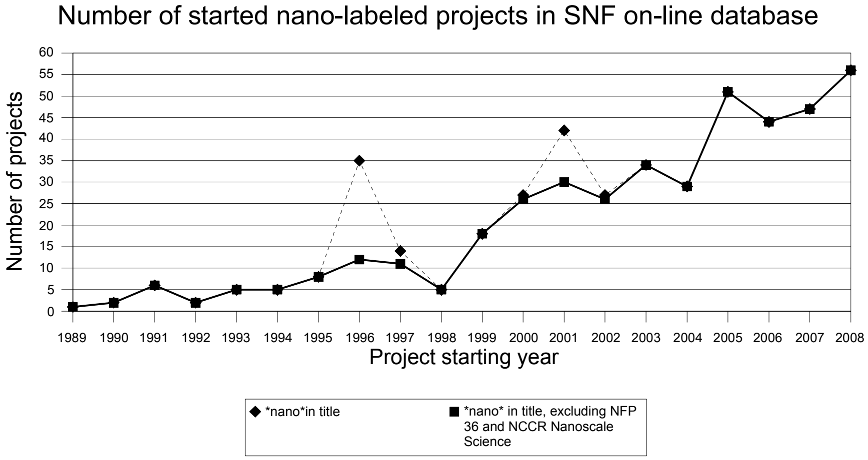

Diagram 4: Number of started 'nano'-labeled projects in SNF's on-line database

Source: SNF (2009b)

SNF's policy was and still is to promote competition, which means not to pursue life time funding. In SNF's view, universities were the institutes to finance stable research structures. But because the universities were not involved in the funding decisions of SPPs, mismatches between universities' policies and the SPP plans could occur.[81]

Finally, splitting the management over SNF and the ETH Board was perceived as a problem. An early evaluation of the program in 1994 by an international expert group criticized the division as expensive. The 2000-2003 White Paper did not mention it, but the previous one did. (Braun & Benninghoff, 2003, p. 1854) (Schweizerischen Bundesrat, 1995b, p. 942 - 943) The 2000-2004 White Paper located the NCCR instrument at SNF exclusively.

When the White Paper was published in 1998, the ETH Board also had decided to launch a successor to the SPPs, called the Technology Oriented Programs (TOP). Both instruments were meant as successors to the SPPs, but the two took different courses. The TOP instrument continued and elaborated on the SPP's aspect of technology transfer, whereas the NCCRs continued on the aspect of building centers of research and embedding them in local policies.

Through both instruments nanotechnology programs were established. This reflects a continuing and gradual growth of researchers' interest in the field. Diagram 4 provides an indication of this trend. It shows the number of started projects per year of projects carrying the nano-label in their title.

[81] Interview with S. Bachmann. Interview with K. Eggenberger. Interview with G. Wagnière and P. Burkhard.

5.5 TOP NANO 21 program

When it became clear that the SPPs would be discontinued, the ETH Board launched a successor instrument with the TOP NANO 21 program. It was the first time that it launched a program instrument on its own initiative. By doing so and by selecting the first program's topic, it deviated from the division of labor and resources that SNF and the Federal Council used for NFPs. From the perspective of the ETH Board, launching the TOP instrument was a natural thing to do, considering its task of governing the ETH Domain as it was laid down in law five years before.

The following subsection provides a condensed history of the ETH Board and ETH Domain. It serves to contextualize the status change of the ETH Board compared to its predecessor, so that the Board's decision to launch a new instrument and select the field of nanotechnology becomes both understandable from the Board's perspective as well as understandable as a new way of research governance in the Swiss context.

A brief history of the ETH Board and the ETH Domain

The ETH law established the ETH Domain and its governing body, the ETH Board as of February 1st, 1993[82]. The Law established the ETH Board as the general governing body of the two ETHs and the research institutes that are part of the ETH Domain, by issuing general targets and policy guidelines. The Board would also provide budget to all organizations in the ETH Domain, approve their development plans and monitor their progress. (Bundesversammlung der Schweizerischen Eidgenosschenschaft, 1991) The ETH Domain's increased autonomy included the right to establish and abolish research units and educational units. Previously, this was a right of the Federal Council. Also, the right to appoint professors, assistant professors and other research and teaching positions was transferred from the Federal Council to the ETH Board. (Schweizerischen Bundesrat, 1995b, p. 870)

In general, the new ETH Law as it passed the Swiss Federal Assembly[83], acknowledged explicitly the ETH Domain's freedom of teaching, learning and research. At the same time, the ETH Domain and the ETH Board did not

[82] It replaced the 1854 law on polytechnics after a long history of adaptations and after an unsuccessful attempt in 1968/1969. A temporary law was put in place and prolonged a few times. In the course of the 1980s the Federal Council developed a new ETH law, which it proposed in December 1987 and which came into force in 1993. (Schweizerischen Bundesrat, 1988, p. 742 - 747)

[83] There were some differences between the proposed law and the law as it passed Parliament. For example the proposed law did not provide the ETHs with status of legal entity, whereas the passed law did.

become completely independent. The members of the ETH Board were appointed by the Federal Council and the ETH Domain was placed under the responsibility of the Federal Department of Home Affairs, which also provides its overall budget.

A new funding instrument from the ETH Board and the selection of nanotechnology

When the Federal Council launched the first six SPPs in 1992, it located three at the ETH Board and three at SNF. The instrument was, so to say and possibly with its consent, imposed on the ETH Board. However, with the extra task also additional money became available and the ETH Board considered it its own. When the SPPs were abolished, the ETH Board members and staff considered a follow up program instrument. To the Board, being the ETH Domain's strategic decision making body, it was the natural thing to do. The Board felt that program funding was an indispensable instrument of strategic planning and prioritization. (ETH Rat, 2001, p. 21; Schweizerischen Bundesrat, 1999, p. 340)[84]

Within the ETH Board, the matter of follow up on the SPPs was discussed in particular by S. Bieri, who had been Vice President of the Board since 1995, H. Rohrer, Board member since 1993, and late H. Neukom director of research. The discussions were part of broader strategy preparation including portfolio analysis and discussions in 1998 and 1999[85].

The Board wanted to start something new, a program that was not limited to the ETHs and the ETH Domain's research institutes, but also addressedother universities and industry[86]. The program also allowed for funding of research outside Switzerland if the research could not be done at a Swiss institute[87] The Board wanted the instrument to allow open competition and to aim for fundamental science with application orientation and for stimulation of higher education[88].

Besides nanotechnology, other themes for the first program were considered and discussed as well. However, the budget was limited and in July 1998, nanotechnology was selected after a proposal by Rohrer and Bieri.[89]

During the years 2000 - 2003, the ETH Board invested about CHF 60 M in TOP NANO 21 (ETH Rat, 2001, p. 21). It reserved these means in the budget of the ETH Domain. KTI invested CHF 10 M in the program[90] and industry

[84] Interview with S. Bieri.
[85] Interview with S. Bieri.
[86] Interview with S. Bieri.
[87] Interview with K. Höhener.
[88] Interview with S. Bieri.
[89] Interview with S. Bieri.
Schweizerischen Bundesrat (1999, p. 340)
[90] Interview with S. Bieri. Interview with K. Eggenberger.

contributed CHF 37 M (ETH Board & Commission for Technology and Innovation, 2005, p. 8). Compared to the ETH Domain's income of around CHF 1.7 billion in 2000, CHF 60 M is a small amount. Compared to NFP 36's budget of CHF 15 M and MINAST's budget of CHF 120 M[91], TOP NANO 21's budget was considerable. For more figures, see Section 5.8.

The ETH Board mandated KTI for program management tasks such as issuing calls, evaluating and granting proposals, information gathering and controlling the projects. (Schweizerischen Bundesrat, 1999, p. 339 - 340).

TOP NANO 21

Because the TOP NANO 21 program is the only nano-labeled funding program which set out to address and combine basic research and technology development at both the program level by a range of funding instruments and procedures, as well as at project level by special requirements, it is described in detail here.

Legitimation and program objective

The program's website (TOP NANO 21, s.a.-a) pointed out that "The outline conditions for economic activity are undergoing radical change" and continued to remark that the "use of the NANOMETER ... offers the prospect of renewal in many branches.". It would offer an opportunity to establish new companies and "serve as the basis for the creation of a brand-new sector of industry". The impact could be expected to be bigger than that of the move from millimeter to micrometers, still according to the website. Including the nanometer into products may provide companies with "a real **competitive advantage**" (emphasis in original). Because Switzerland is a leading country in the field of nanoscience, it should become a pioneer in developing technologies and industrial applications. Finally, the program's website argued that society is demanding job security which is under pressure due to increased productivity. It indicated that the nanometer scale potentially offers a contribution to the creation of jobs and to job security through "extending the scope of added valuation".

The program's main objective was to "strengthen the Swiss economy through the application of new technologies based on the NANOMETER." The program wanted to create a technology platform, which was described as consisting of "theme based centers of competence". The program also aimed to integrate the nanometer into teaching in order to stimulate the development of future scientists, researchers and engineers. Next, the program aimed

[91] Including contributions from industry.

> " to bundle the strengths and resources of all interested specialists to be found in Switzerland towards economic usage through the creation of new technologies and the development of new products and services as well as the consolidation of existing products." (TOP NANO 21, s.a.-a)

Finally, the program wanted to stimulate both "pure research" and creation of new technologies and solutions for economic problems. Therefore, protection and exploitation of intellectual property was a major objective. (TOP NANO 21, s.a.-a)

Definition and subdivision of nanotechnology

TOP NANO 21's website did not publish a particular definition of nanotechnology that projects had to comply to. It noted that the nanometer as selection criterion always arouses discussion. So, instead of a definition, the program provided a list of criteria of nano aspects to help applicants. The final decision on the nano-relevance of a project was left to the Group of Experts which also evaluated its scientific quality (see below). (TOP NANO 21, s.a.-b)

The list of 'some criteria for the nano-aspect' contained six headings, viz. material, chemistry, methods, components and systems. Each was accompanied by a description or list of possible criteria. For example, under 'material' and 'chemistry' it was required that at least one of a list of five criteria should be addressed in a significant way. Among these five were "Accurate control or choice of processes, growth, distribution etc. on the nm scale.", "Central significance for the production of macro, micro, and nano-components and systems." and " 'Self organization' forms an important element of the new functions and characteristics." (TOP NANO 21, s.a.-b). One other example, under the heading 'Systems' it was mentioned that "The nano-aspects should generally surpass a micro piggyback electronic system (standard microelectronics with a microtechnology component)."

This latter aspect reflected the Steering Committee's wish to steer away from the overlapping zone with microtechnology. In the course of the program, actors realized that to upscale from the nano level, one has to pass the micro level.[92]

The sixth heading introduced aspects that might lead to a rejection of proposals. Among other things, it was discouraged to dress up research that was already going on in 'nano-clothing' rather than including new aspects of the nanoscale, to continue or copy projects from previous nanotechnology programs, or to attempt to continue research groups that were the result of earlier programs.

This approach without an overall definition or description, the list of helpful criteria and the list of warnings was the idea of the program's scientific

[92] Interview with K. Höhener.

manager, H.J. Güntherodt, who was particularly keen on attracting new research proposals.[93]

Bridging nanoscience and nanotechnology
The program's website did distinguish between science and technology development, as illustrated in the list of program objectives. Conceptually, the program saw nanotechnology as developing from nanoscience: "As we have already seen from conventional technologies, nanotechnology will develop from the nanosciences." (TOP NANO 21, s.a.-a).

It should be noted that although the program used a separation between concepts of science and technology, it did not highlight this in deliberate use of the terms 'nanoscience' and 'nanotechnology'. Instead, it used the term 'nanometer' to identify its field of operation. To illustrate this, a central page[94] on the TOP NANO 21 website uses the terms 'nanoscience' and 'nanotechnology' five times each, whereas the term 'NANOMETER' (consistently written in capitals) occurs 46 times (TOP NANO 21, s.a.-a).

The program aimed to enforce addressing the two types of research by requiring each project proposal to address fundamental research, technology development and application development. The website visualized this as a three dimensional structure, as presented in Diagram 5. This was one of the program's main instruments to bridge the distance between research and industry. Its management noticed that such bridging was not easy to accomplish. It noted that the two operate in different ways, with different time scales and different languages.[95]

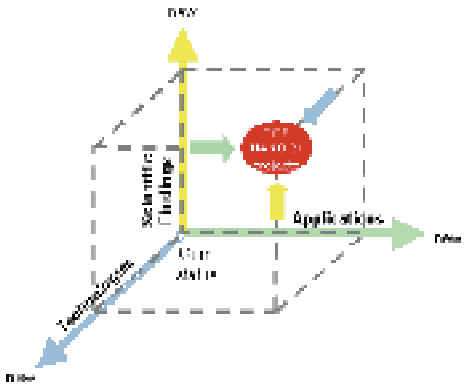

Diagram 5: TOP NANO 21's three dimensional project structure

Source: TOP NANO 21 (s.a.-a)
(Reproduced with permission)

If an application did not address all three dimensions then it was rejected. In the course of the program, it appeared that the science was underdeveloped. So-

[93] Interview with K. Höhener.
[94] TOP NANO 21 used a website for all its communication. The page functioned as program brochure / implementation plan.
[95] Interview with K. Höhener.

called technology-oriented projects were allowed to fill the gap without the requirement to address all three dimensions.[96]

TOP NANO 21 operated eight types of funding instruments: technological fundamental projects, feasibility studies, alliance projects, individual projects, projects for knowledge and technology transfer, projects for the preparations for launching new companies, strategic projects, and special projects (TOP NANO 21, s.a.-a). From this list alone it becomes clear that the program was dedicated to the development of nanotechnology for application in industry. One should however keep in mind that in the first four instruments projects had to comply to the three dimensional structure set out above, in which one dimension was reserved for the development of basic scientific knowledge.

The different instruments do stress different dimensions. For example, the so called technological fundamental projects were meant to "increase levels of knowledge and should focus on the creation of new technologies or the consolidation of existing technologies" (TOP NANO 21, s.a.-a). Feasibility studies focused more on the economic dimension. They were meant to provide insight in the feasibility of risky new ideas and concepts, and their economic potential. A company could apply for a feasibility study when it was interested in a particular potential of a new functionality of a nanotechnology or technological solution for a problem. The study would then involve scientists who would study the question whether that technology could provide a solution within a limited time span.[97]

Some project types involved cooperation between industrial partners and researchers from public research institutes and universities, or knowledge transfer from the ETH Domain and the universities to industry and the Universities of Applied Science[98]. In exceptional cases, foreign companies were allowed as project partners, provided the Steering Committee approved, and provided the companies contributed to considerable degree to the project budget. (TOP NANO 21, s.a.-a)

Strategic projects could be launched by the Steering Committee, the program management or the Innovation Committee. The projects were defined through a top down, rather than a bottom up process and covered areas new to Switzerland. (TOP NANO 21, s.a.-a)

Organization of the progrm

The ETH Board delegated the program management to KTI. Because KTI at that time was understaffed, it delegated the program administration to a consultancy firm called Temas. The program had a scientific director and a

[96] Interview with K. Höhener.
[97] Interview with K. Höhener.
[98] Universities of Applied Science are schools for the training of professionals in technical domains.

director for economic affairs/technology transfer. Güntherodt was selected for the function of scientific director because he had experience as the program director of the MINAST program[99]. K. Höhener, director of Temas, was the director for economic affairs and the administrative director of the program.

Güntherodt and Höhener had about half a year to design TOP NANO 21's implementation following guidelines from the ETH Board. The preparations involved a survey of Swiss industry and research to see which companies and research institutes were involved in various aspects of nanotechnology and to analyze their potential. This resulted in a list of 140 companies. Güntherodt and Höhener analyzed and visited up to a hundred companies in order to bring nanotechnology and the funding program to their attention. The two program managers considered this necessary because nanotechnology was in an early phase of its development and many companies, being relatively small, do not monitor the opportunities of nanotechnology research. If the visited companies became interested, then Güntherodt and Höhener would bring them into contact with research groups that might fit the companies' particular interests. After that, it was up to the companies and researchers to develop ideas and project proposals.[100]

In the course of the program, applicants could send in their proposals at any time and review of the proposals was an ongoing process taking from six weeks to three months depending on the type of project. The review procedure could involve two phases. In the first phase, the application would be a project outline only. Güntherodt and Höhener checked them on basic administrative requirements in order not to overload the Expert Group. This resulted in an advice to the applicant who could then decide whether or not to send in a full proposal. Applicants could however also skip the first phase and send in a full proposal directly. During the second phase the Expert Group evaluated full proposals on scientific quality and Höhener evaluated the economic quality/viability. The reason for this separation was that foreign experts were not expected to be fully aware of the local economic situation. Besides international scientists, the Expert Group also included representatives of KTI and Rohrer acted as advisor to the group. The scientific and economic assessments went to the Steering Committee, which made the final decision. It consisted of ETH Board's vice president, KTI's president and two or three executives from industry.[101]

Besides the Expert Group and the forum, the program had a so called Innovation Committee which consisted of representatives from academic research and industry[102]. The TOP NANO 21's program managers reasoned that

[99] Interview with S. Bieri.
[100] Interview with K. Höhener.
[101] Interview with K. Höhener.
[102] For a full list, see: TOP NANO 21 (s.a.-c)

companies are interested in short term solutions which last two to three years. To generate ideas with a time horizon of five to ten years, they created the Innovation Committee, which had to develop visions of future research, technologies and applications. The Committee's ideas were made public and calls were opened for research groups to show their interest. The groups could then apply for a technological fundamental project without the need for an industry partner. The Innovation Committee came up with topics such as tribological surfaces and self organization of molecules. One unexpected result was that parties represented in the Committee started to collaborate on projects themselves, either or not funded by TOP NANO 21.[103]

Members for the Innovation Committee and the Expert Group were identified and recruited by Güntherodt and Höhener who, as one of them noted, simply knew whom to ask. Identifying the candidates took less effort than convincing them because most were time pressed. To each candidate the program managers had to show what the candidate's interest in the program could be.[104]

Projects could start as of January 2000. As scientific manager of the program, Güntherodt monitored the projects' progress. If necessary he could change them, stop them or provide them with additional money. Through the project review activities, Güntherodt could also establish new contacts between groups that had not been in touch before the TOP NANO 21 program.

Besides the research projects, there were a number of other activities organized within TOP NANO 21. These included so called road shows to locations in the United States and the US, support to PhD students who were unable to finish their PhD within project time, regional seminars to stimulate regional development of nanotechnology, and marketing, road mapping and other services to companies.

During TOP NANO 21's running time, also the NCCR Nanoscale Science was launched. In this program, Güntherodt was the first director, so he knew what happened in both programs and this allowed him to coordinate the two. However, he had little work on that because of the different foci of the two programs.[105]

TOP NANO 21 officially ended by the end of 2003. Some projects had not finished by then, so the program's administration was handed back to KTI.

TOP NANO 21 remained one of a kind because the TOP instrument was abolished after TOP NANO 21. The reasons given for this sudden halt are mixed, if provided at all. The ETH Board's 2004-2007 strategic plan merely

[103] Interview with K. Höhener.
[104] Interview with K. Höhener.
[105] Interview with K. Höhener.

mentioned that no further research program would be launched (ETH Rat, 2003, p. 20). Interviewees suggest different reasons such as the overall financial situation of Swiss federal research funding, a change of Board members in the ETH Board, or the estimation that the program was too early[106].

Although the ETH Board abolished the TOP instrument, nanotechnology remained high on its agenda, as is illustrated by its 2004-2007 strategic plan (p. 20). KTI also continued on the theme when it launched a follow-up program on Nanotechnologies and Microsystems technology (Schweizerischen Bundesrat, 2002, p. 2430). See Table 3, starting p. 98 for financial details.

5.6 NCCRs and NCCR Nanoscale Science

TOP NANO 21 was the ETH Board's successor of the SPP instrument. SNF also had developed a successor instrument which focussed on establishing centers for research which would remain in existence after SNF's funding would cease. To achieve this effect, the leading applicants' respective home institutes or universities were included in the selection procedure. Because it required that applications would build on already developing research, it opened up an excellent opportunity for the group of nanotechnology researchers who had been involved in MINAST and NFP 36.

SNF started developing plans of the NCCR instrument around 1995 and its first round ran parallel to TOP NANO 21, so this section starts by taking a step back in time.

Development and outline of the NCCR instrument

SNF started developing an alternative to the SPPs before the first round of SPPs had finished. In 1993 and 1994, the Swiss Science Council organized an evaluation of the early SPPs by a group of international experts. Among other things, the expert group criticized the lack of connections between the competence centers that were established through SPPs on the one hand, and the universities and ETHs that housed the competence centers on the other. It advised that these universities should be obliged to acknowledge the competence centers. (Schweizerischen Bundesrat, 1995b, p. 943)[107]

[106] Interview with S. Bieri. Interview with K. Eggenberger. Interview with K. Höhener.
[107] Interview with S. Bachmann..
See (Braun & Benninghoff, 2003) for more details about this story.

Responding to this evaluation, SNF's director, H.P. Hertig, designed a new instrument which basically aimed for the same goals as SPPs but in a different and more effective way. He based his design on similar instruments in the United States and Germany. The design was informally discussed within and outside SNF and eventually the Federal Council adopted it in its research policy White Paper for 2000 to 2003.[108] This successor to the SPPs was the NCCR[109] instrument.

In order to make the NCCR instrument attractive to politicians, a list of fields for proposals in the first round was issued. It consisted of life sciences, humanities and social sciences, sustainable development and environment, and information and communication technologies. Besides these four themes, the list also included the category 'other'. The list was designed to be familiar to members of parliament and to connect to European Union priorities. Some politicians wanted a more specific list, but SNF managed to keep the themes quite broad and in this way keep flexibility. Also, the Office of the Secretary of State of Education and Research was not in favor of a more specific list.[110]

NCCRs were meant to enhance the position of promising fields of research through establishing a national center of competence and a national network for their respective fields. The instrument attempts to achieve this by requiring that a community of some size already exists in Switzerland, and that the topic is not already disappearing from research agendas. In addition, SNF finances 30% to 50% of an NCCR while requiring the host university or ETH to match the remainder and to continue funding after SNF's support ends. SNF funds NCCRs for twelve years in blocks of four years. After that period, the host university is required to sustain the NCCR by its own means or through additional funding acquired from other parties such as industry, cantons or cities.[111]

During the first twelve years, an NCCR's leading house is the center of its field's network of Swiss researchers. A leading house is the managing and administrative center of an NCCR at its host university. Coordination of research in the network is, to a large extent but not exclusively, achieved through project funding.

After SNF has stopped its contribution, it expects the leading houses to have grown into a nationally and internationally visible center of gravity for their respective fields in Switzerland. In twelve years, things like chairs, facilities and courses are expected to have been established and to survive after NCCR funding, but SNF does not expect the NCCR to survive as a network.[112]

[108] Interview with S. Bachmann.
[109] See footnote 78 about the name of the instrument.
[110] Interview with S. Bachmann.
[111] Interview with S. Bachmann. Interview with K. Eggenberger.
[112] Interview with S. Bachmann. Interview with K. Eggenberger.

The selection procedure, although different from the NFP's, still showed a similar division of labor and resources. In addition, because the host university was required to match budget and continue the NCCR after funding stops, it was included in the procedure. Here, the procedure of the second round is sketched. A few experiences from the first round are added in footnotes.

SNF started the procedure by placing a call for pre-proposals[113]. Pre-proposals were twenty to thirty page outlines including preliminary project proposals[114]. A group of 15 international experts provided a global feasibility evaluation of all pre-proposals. This resulted in advice to applicants about their estimated chance of success[115].

In the next phase of the review process, applicants sent in full project proposals including project details, time schedule and budget. These were distributed over seven specialists committees for evaluation. Each committee included two foreign experts in fields close to the proposal, one foreign generalist and three SNF representatives. The generalist was added in order to avoid a battle of disciplines within the committee. The SNF representatives had no vote and remained at the background in the discussions. The committees wrote short evaluations of the proposals which were discussed during a two day evaluation session in Bern. At this session, lead applicants were invited to present and discuss their proposals. This evaluation round resulted in an advice to SNF about each proposal.[116]

SNF sent a shortlist of highly rated proposals to the Federal Department of Home Affairs which then had to narrow down that list because the budget did not, as it usually does not, allow to fund all proposals[117]. At this point science policy views could be invoked including criteria such geographical spread or equal representation of language areas.[118]

When SNF developed the NCCR instrument and discussed it with the Department, SNF successfully negotiated that the Department could not add proposals to SNF's shortlist. This way, lower ranked proposals could not be prioritized for political reasons. SNF was quite sensitive to the issue, because

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113 In the first round, a call for letters of intent preceded the call for pre-proposals. SNF wanted to get an idea of what might be proposed. That resulted in about 230 letters. It appeared that an erroneous rumor existed that one had to apply if one wanted to have a chance of any future SNF funding.

114 During the first round, it turned out that pre-proposals diverged too much in terms of specificity, which is why SNF added the requirement.

115 It could be either A, B or C. A meant that the proposal had a good chance to succeed. B meant that if certain problems were fixed, then it would have a good chance to succeed. C meant that the proposal had too many problems which could not be expected to be fixed in time.

116 Interview with S. Bachmann.

117 During the first NCCR round, researchers submitted 230 letters of intent, followed by 82 pre-proposals, followed by 34 full proposals. SNF presented a short list of 18 full proposals to the Federal Department of Home Affairs which dropped 4 from that list. The second round saw 44 pre-proposals, 17 full proposals and 6 granted proposals. (SNF, 2007, p. 5)

118 Interview with S. Bachmann.

the NCCR instrument was the first in SNF's existence in which SNF did not have the final decision.[119]

The Department made its selection based on presentations and meetings with applicants and the rectors of their institutions. At that point, universities that had more than one proposal still in the competition, had to decide which one to back because they could not support all[120]. After that, the Minister made the final decision and SNF handled the administrative affairs.[121] This role is more limited than for NFPs because the NCCR's leading houses have a high level of autonomy.

SNF's Division IV, launched the first round's call in January 1999. A few proposals originated from groups involved in SPPs and this was also the case with the Nanoscale Science[122]. Güntherodt was the main applicant. Within his university, he managed to contact and convince enough researchers to arrive at a critical mass necessary for a leading house. In addition, through his experience with earlier programs such as NFP 36 and MINAST, he knew his way around in Switzerland[123]. In December 2000, the Nanoscale Science proposal was granted together with 13 others.

NCCR Nanoscale Science

The NCCR Nanoscale Science does not work with one particular definition. Its website provides an explanation to the lay audience of what is meant: "Nanoscale science and nanotechnology deal literally with the small things in life. One million of the objects studied would fit onto the dot of this “i”." (SNI, s.a.-c). The page also describes a nanometer as a billionth of a meter. It continues to position the field of nanoscale science as a result of breakthroughs with new materials, such as carbon nanotubes, and new microscopes such as the scanning tunneling microscope and other scanning probe microscopes.

Although the website provides a description of nanoscience which remains quite close to the instruments that opened the field, the NCCR's current director, C. Schönenberger[124] pointed out that the leading house in Basel is

[119] Interview with S. Bachmann.

[120] One effect of this seemed to be that all universities in this position favored the proposals in the natural and life sciences over the proposal in the humanities and social sciences. In the first round only two out 14 winning proposals were located in the latter group. For this reason, the entire second NCCR round was dedicated to these fields.Interview with S. Bachmann.

[121] Interview with S. Bachmann. Interview with K. Eggenberger.

[122] Interview with S. Bachmann.

[123] Interview with S. Bachmann. Interview with C. Schönenberger.

[124] Schönenberger had been a PhD student at IBM in Zürich when the STM was invented, and in those days mentored by Rohrer. Schönenberger had worked on the development of the first atomic force microscope. Later, he joined the NFP 36's expert committee. At that time worked with STMs at Philips in the Netherlands and was in the process of moving back to Switzerland and becoming

specialized in the sub fields of quantum information processing, molecular sciences and molecular biology, which limits the NCCR's coverage in Switzerland.

The resulting list of modules identified within the NCCR is: nanobiology, quantum computing and quantum coherence, atomic and molecular nanosystems, molecular electronics, functional materials by hierarchical self-assembly, and applied projects in nanoscience and nanotechnology.

The NCCR's program title, Nanoscale science, positions the NCCR in nanoscience, rather than nanotechnology. Schönenberger notes that there still is enough basic science to be done at the nanoscale. He argues that he does not know how the field will develop and that it may end up as an engineering discipline.

The NCCR mainly focuses on basic science, but as other NCCRs, it also pays attention to technology transfer. Industrial partners are involved in projects and by the end of 2008, the NCCR had three spin off companies (SNI, s.a.-a, s.a.-b).

From 2001 until and including 2008, the NCCR Nanoscale Science received around CHF 5 M annually from SNF, about CHF 7,5 M annually from the leading house and other research institutes and universities, and about CHF 3 M annually from industry and other third parties. (SNF, 2004, p. 36; 2007, p. 6 - 7, 45) See also Table 3 on p. 98. As of 2006, the canton of Aargau invested CHF 5 M annually into the NCCR and will continue to do so after SNF funding will cease. The condition to this investment is that most of it is spent on user oriented research in collaboration with the University of Applied Science Nordwestschweiz and the Paul Scherrer Institute. (Kaufmann, 2005)

The program basically operates through project funding and most projects were basic research projects. The projects in the module of applied projects in nanoscience and nanotechnology were financed through the canton of Aargau's investments. The call for these projects required that projects would bridge the gap between basic research as typically funded by SNF, and product oriented research as KTI would finance (SNI, 2007). Another requirement was, as mentioned above, a cooperation involving at least two out of the three designated institutes, viz. University of Basel, the University of Applied Science Nordwestschweiz and the Paul Scherrer Institute. In addition, at least one private enterprise had to be involved, which preferably would be based in Basel or one of the surrounding cantons[125].

NCCR Nanoscale Science will continue to run with SNF funding until 2012 and if the canton of Aargau continues its support, then it will continue to have some

professor. Schönenberger succeeded Güntherodt as director of the NCCR.

[125] These were Basel-Stadt, Basel-Land, Aargau and Solothum

programmatic funding possibilities after 2012. It is not the last funding program on nanotechnology in Switzerland. In 2008, the ETH Board, the two ETHs and research institutes from the ETH Domain, a number of universities and universities for applied science together launched a new funding program called Nano-Tera (ETH Rat, 2008). This program focussed on electrical and mechanical micro and nanosystems, with emphasis on data storage and processing systems of terabyte magnitude. In the program, also SUK and SNF are involved. The first added CHF 20 M to the ETH Board's CHF 40 M contribution. The latter is responsible for evaluation of scientific quality of regular research project proposals (Bradley, 2008, p. 8).

5.7 Conclusion: bottom-up and top-down through business-as-usual

SNF's response to the emerging field of nanotechnology was of a business-as-usual type in which SNF has no role of prioritizing fields of research. For this, it is dependent on resources provided by others. Researchers provide priority proposals and Ministries decide which priorities are important. In this prioritization process, SNF is, so to say, by-passed as a routine.

Its role is that of process manager and program manager, and in case of NFPs of providing a feasibility evaluation. Its interest is in championing a transparent process of bottom-up proposals, scientific peer-review and top-down selection. It also guards the role of scientific peer-review to make sure that it is not overruled by top-down selection, but has an at least equal share in the selection process.

Thus SNF 'responded' to changes in researchers' resource needs related to nanotechnology by guarding a business-as-usual process that allow researchers to articulate these needs in competition. This worked well in the sense that it supported one of the first nanotechnology labeled funding programs in Europe. To the case more interesting is that NFP 36 also was the first in Switzerland, in a row of eventually six programs. A striking feature of the Swiss case is that members of the group of researchers involved in NFP 24 and NFP 36 were also involved at high levels in other, parallel and later programs.

This undoubtedly had to do with smart networking and political skills of members of this group. However, it cannot explain how this passes peer-review, whereas SNF's open system provides the additional explanation in terms of resources. NFP 36 could continue building on the success of NFP 24, and these programs not only gave shape to the meaning of nanotechnology, they also supported the creation of research capacity, skills and high quality research that could pass peer review. By the end of the 1990s, when both NFP 36 and MINAST were ending, nanotechnology had gradually become noticed within and outside research. This meant a further wish to continue such research and the programs had helped to put in place a research landscape which could further the field. Thus when new instruments, viz. the TOP and NCCR instruments, were launched, Swiss nanotechnology was in good shape because of earlier resource investments.

Although TOP NANO 21 can be considered a response to researchers' wishes to continue on the field of nanotechnology, it was not the result of a bottom-up processes as managed by SNF, but of top-down decision making. The ETH Board identified nanotechnology in a way similar to how science RFOs in other countries develop research priorities and funding programs: while taking input from research into account the Board defined the program in outline and a small program management team further developed and implemented it.

Because the only TOP program ever launched was TOP NANO 21, it might seem that the program was the ETH Board's tailor made response to nanotechnology. However, the TOP instrument was meant as an instrument to address priorities in the governance of the ETH Domain. The Board outlined the general design of the instrument, and only after the Board had identified nanotechnology as the field for the first program, was it further tailored.

It had a firm orientation on technology development, but it also addressed basic research in nanotechnology. The program included funding instruments that stress particular types of research and application development, including business development instruments. At project level it combined intentional development of nano-scale related functionalities, basic research and application development through proposal requirements in a number of its instruments. Also through other means such as the Innovation Committee and requirements such as cooperation between a public research group and a private company did the program try to address both types of research within individual projects. In this respect, the program stands out among others described in this thesis.

When the ETH Board launched a program funding instrument it acted as an RFO, but because it was a governing Board for institutional funding of the ETH Domain it was free to cross the science-technology divide as it saw fit. RFOs, such as the Finnish science RFO and technology RFO cooperated on nanotechnology but eventually kept programs positioned at either side of the divide.

5.8 Figures of the Swiss case

Table 3: Overview of incomes and budgets of Swiss RFOs and nanotechnology programs (x 1 000 000)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF
SNF										
• Income from State			1262[126]				1294[127]			
• NFP 36[128]						15				
KTI										
• Income from State			202[129]				322[130]			

126 Source: Schweizerischen Bundesrat (1995b, p. 855, 910, 951). Including NFPs and SPPs at SNF.
127 Source : Schweizerischen Bundesrat (1999, p. 429)
128 Source: (SNF, 1994)
129 Source: Schweizerischen Bundesrat (1995a, p. 784)
130 Source : Schweizerischen Bundesrat (1999, p. 429)

Table 3 continued

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF	CHF
SNF										
• Income from state[131]	1467				1951					
NCCR Nanoscale Science[132]										
• From SNF		3	4	6	6	5	5	5	5	-
• From leading house university		4	3	8	8	1	1	1	1	-
• From participating universities		1	1	2	2	7	6	6	6	-
• Third parties		3	4	3	3	3	3	3	3	-
• Aargau canton							5	5	5	5
KTI										
• Income from State[133]	308				403					
Micro and Nanotechnology										
• From KTI					16	18	19	21	17	
• From industry					19	29	25	27	26	

Continued on next page

131 Source: Schweizerischen Bundesrat (2003, p. 2371; 2007, p. 1231)

132 Sources for all data except contributions from Aargau canton: SNF (2004,p. 36; 2007, p. 45). Aargau canton contributions: Kaufmann (2005)

133 Source: Schweizerischen Bundesrat (2003, p. 2371; 2007, p. 1231)

Table 3 continued

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
The ETH Board										
• Total income[134]	2056	2117	2171	2202	2232	2307				
TOP NANO 21[135]										
• From the ETH Board	60									
• From KTI	10									
• From industry	37									

[134] Source: Annual reports 2001 - 2005
[135] Source: ETH Board & Commission for Technology and Innovation (2005, p. 8)

6 Finland: bridging the science-technology divide

6.1 Introduction

Finland is well know because of Nokia's success as a producer of mobile phones for the European GSM network and its economic development over the passed two decades. In science, technology and innovation studies, it is particularly known because it is one of the first countries to base its policies on the national systems of innovation approach (Freeman, 1982; Lundvall, 1992; Nelson & Rosenberg, 1993). Whether or not this is the basis of Finland's recent economic development remains unanswered here[136]. As far as RFOs are concerned, Finland shows no divergent structure from the Netherlands and Switzerland: it can be characterized as a science-technology divide with two RFOs, the Academy of Finland and Tekes, financed by ministries for science and education and for economic affairs respectively.

Tekes and the Academy explicitly cooperated when they ran their nanotechnology funding programs, which did not occur in the other two countries. The first occasion was during a three year program in the late 1990s. Together, the two RFOs planned and financed one program, the Nanotechnology Research Programme, it was not only claimed to be the first such program, but also the first program which addressed "both scientific and technological issues" (Tekes 2000, Preface).

Their second cooperation on nanotechnology consists of two parallel but separately operated programs with the same name, FinNano, which started around 2005. Cooperation, among other things, consists of information exchange about program activities, exchange of project proposals between the two RFOs, mutual co-invitation of researchers from the other program to program activities and joint annual seminars. In addition, the two have a representative in the other's FinNano program board, and they jointly receive foreign parties interested in Finnish nanotechnology.

The cooperation is interesting for two reasons. Firstly, it reflects nanotechnology's appeal to both basic research and technology development. A joint program or parallel programs indicate that both are taken seriously at the same time. The second reason is that although it is often argued that the

[136] For an answer, see Georghiou, Smith et al. (2003, p. 80)

distinction between basic science and technology development/applied research is difficult to make, that the linear model is not realistic, institutional structures that reinforce these distinctions remain in place. The cooperation between Tekes and the Academy can be seen as an attempt to bring change on that point.

Most definitions of nanotechnology do not emphasize nor mention the blurring of the border between science and technology, but authors in science and technology studies do. Recently, Bonaccorsi (2008, p. 295) argued that nanotechnology and other recent fields of research cannot be practiced without researchers designing their object of study and constantly moving between design and knowledge production. If so, then nano research may suffer from the science-technology divide, unless institutional change occurs.

The cooperation between the Academy of Finland and Tekes was in part triggered by arguments that the boundary between basic and applied research had become unclear. Other reasons were external pressure from politicians and internal deliberations about research funding in general. Nanotechnology was the first occasion in 1997, but afterwards the two RFOs cooperated on other programs and in other ways as well (Pelkonen, Teräväinen et al., 2008, p. 249).

It also turns out that the FinNano cooperation did not result in a joint understanding of nanotechnology and of the relation between nanoscience and nanotechnology. In fact, the programs were developed separately and cooperation started late during development. From the above mentioned view of blurring of boundaries, it is remarkable, because the cooperation does not show signs of such blurring. However from resource dependence perspective, the shape of the cooperation is perfectly understandable. To show this, this chapter delves into differences in environment enactment, response development and resource dependencies of the two RFOs.

In addition, these details also show that and how the exact shapes of the funding programs largely depend on the RFOs resource dependencies and related organizational structures.

6.2 The Finnish research funding constellation

Outline of Finnish research funding and industry

With Nokia's success in mobile telephony in the 1990s, it gave an impulse to the Finnish economy and a boost to Finnish information and telecommunications industry. However, it would go too far to completely attribute Finland's economic uprise to that. Its industrial structure had been changing in the previous decades.

During these decades, Finland's main exports were dominated by paper products, wood and metals. These were Finland's traditional export products. In 1960 they amounted to around four fifth of the export. Since then, the export diversified and this process continued throughout the 1990s. Initially the shares of chemical products and engineering and metal products increased and as of the 1980s electronics and electrical industries gained importance. In 1997 they made up about one quarter of Finland's export. By then, the traditional three export products still added up to almost forty percent. (Ormala, 2001, p. 330)

Compared to other countries, Finland was a late starter in science and technology policy. As of the 1970s public and private actors stressed the need for a 'science and research policy' but in 1980 investments remained as low as 1.1% of gross domestic product. (Alestalo, 1985, p. 279 - 281) In the course of the 1980s, attention for science and technology policy picked up and investments rose to around 1.5% in 1985, passed 2% around 1991, and kept increasing in the course of the 1990s to 3% in 1998 (Ormala, 2001, p. 329). In the early 2000s, the increase continued but then stabilized to a level of around/just below 3.5 % (Academy of Finland, 2009, p. 8).

In 2008, Finland has 20 public universities, including three for business administration, three technical universities and four arts universities. In addition, there are 28 polytechnics and 19 research institutes (Pelkonen et al., 2008, p. 245).

The financing of Finnish public research is framed in two policy making processes. The influential Science and Technology Policy Council discusses the outlines of national research policy and funding affairs. It was established in 1987 as the successor of the Science Policy Council. (Ormala, 2001, p. 334 - 335)

Secondly, the government's four year program formulates budget and policy guidelines of all policy fields, including research. For each year's budget, the Ministry of Education bilaterally discusses plans and negotiates with the universities, research institutes and the Academy of Finland. To launch the discussions, which are known as the 'spring meetings', the organizations are invited to propose plans and the Ministry also makes policy suggestions. Because of this setup, the Ministry has to review tens to hundreds of proposals.

Universities finance facilities and equipment via their regular budgets and negotiate for that via the spring meetings.[137]

The Finnish science-technology divide

Finland's constellation of RFOs can be characterized as having a science-technology divide. It operates a science RFO called Suomen Akatemia (Academy of Finland) and a technology RFO called Tekes[138].

Starting on the science side, in 1961, six disciplinary research councils were established. This marked government's then growing interest in research policy. Another indication is the launch of the advisory Science Policy Council three years later. By the end of the 1960s, the six research councils were merged into one organization, viz. the Academy of Finland[139]. Its tasks were financing of research, research training, and international scientific cooperation. Furthermore, it had to promote publishing and other activities of scientific societies and promote cooperation of researchers. Finally, it had tasks in policy planning and policy advice. The Academy of Finland did not operate its own research institutes. (Lemola, 2002, p. 1484; Seppällä & Müller, 1985, p. 106, 109 - 110)

The Academy of Finland used open project funding mainly but it also earmarked parts of its budget to develop particular fields of research. Between 1971 and 1976, the share of this earmarked research increased from three to twenty five percent[140]. Most of the earmarked funds followed the prioritized areas set by the Science Policy Council. Between 1976 and 1979, it decreased again to fifteen percent. (Seppällä & Paczolay, 1985, p. 87) As of 1979, Finnish Parliament decided that a share of the Academy of Finland's funding should be aimed at basic and applied research which promoted Finland's production. This share started with four percent in 1979, increased to twenty eight percent in 1981 and dropped to twenty one percent in 1983. (Seppällä & Paczolay, 1985, p. 87)

[137] Interview with E. Heikkinen and P. Kauppinen.

[138] Towards the end of the 1960s, SITRA, the Finnish National Fund for Research and Development was established by parliament. This organization, which reports directly to parliament, has had several tasks, some of which were handed over to other agencies or ministries. In the 1970s, it dealt with environmental policies and energy policies. These issues were handed over the Ministry of Environment and the Ministry of Trade and Industry respectively. Later in the 1970s, SITRA focused on industrial research and development. After this issue was moved to Tekes, SITRA mainly has been acting as promoter of economic development through capital investment and seed-finance and working on issues as globalization, commercialization of research and development, studies of innovation systems and future developments. (Ormala, 2001, p. 335 - 336) Although SITRA initially acted as a research funding organization, it will not be further discussed because it moved away from research and technology funding per se in the second half of its existence.

[139] This was a replacement of the Academy of Finland that was established in 1947 (Academy of Finland, 1996, p. 20)

[140] This is the share compared to the Academy's 'non-committed' budget. Unfortunately,

Until 1994 when it was reorganized, the Academy of Finland comprised the Research Council for the Humanities, the Natural Science Research Council, the Medical Research Council, the Research Council for Agriculture and Forestry, the Research Council for Technology, the Research Council for the Social Sciences, and the Research Council for the Environmental Sciences[141].

The 1994 reorganization was the denouement of around five years of forestallment and discussion about the Academy of Finland's structure. One argument to reduce the number of councils was to reduce the number of projects that were difficult to localize as a result of increasing interdisciplinary research. The new number of councils was topic of debate, but eventually Finnish parliament decided on a setting with four research councils, viz. the Research Council for Culture and Society, the Research Council for Natural Sciences and Engineering, the Research Council for Health and the Research Council for the Environment and Natural Resources. In this new setting some areas of research, such as molecular biology, were still shared by two or more research councils. (Academy of Finland, 1996; Dresner, 2001, p. 120; Skoie, 2001, p. 36 - 37)

In 1983, a technology RFO named Tekes[142] was founded as a result of a new science and technology policy which aimed for exploitation of new technologies to arrive at economic growth and increased employment (Lemola, 2002, p. 1484). Until 2008, Tekes was financed by the Ministry of Trade and Industry, which in 2008 merged into the Ministry of Employment and the Economy.

Compared to technology RFOs in other countries, Tekes operates more independently from its budget provider. Its board contains Ministerial representatives, but the Ministry steers through discussions and deliberations. Tekes can make its own decisions about priorities, funding programs and instrument development[143]. (Pelkonen et al., 2008, p. 246 - 247)

Until 2005, Tekes had a matrix organization with divisions for particular technologies, but Annual reports do not map Tekes's funding programs to these divisions. Funding decisions are made by Tekes's Board. As of 2005, Tekes was reorganized into a matrix structure in which all technology areas were merged into one division for particular technologies. The 'vertical' axis of the matrix contains the Activation[144] division and the Project Funding division. The

[141] Apparently, in the course of time, one council was added to the initial six, which probably was the Research Council for the Environment and Natural Resources. I have no data confirming that, nor on the year of its launch.

[142] In English Tekes was referred to as Development Centre of Technology in 1983 (Seppällä, Tolnai et al., 1985, p. 107) and Technology Development Agency in 2001 by Ormala (2001). Tekes's on-line English annual reports from 2000 up to 2004 use the subtitle National Technology Agency, whereas its 2005 and later reports use Finnish Funding Agency for Technology and Innovation.

[143] Pelkonen refers to others who point out strong informal communication ties.

[144] This division "activates [Tekes's] current and potential customers to develop and introduce new technology and to reform their business operation, to succeed and grow on the international

'horizontal' axis contains the divisions Technology and Research Areas, Regional Network, and International Networks (Tekes, 2006, p. 20)

Research projects are owned by universities and public research institutes, although companies can participate in the projects. Tekes can fund such projects completely, but usually requires companies and research organizations to invest about forty percent. The universities or research organizations may apply for patents based upon knowledge created through these projects. If they refrain from doing so, participating companies have the first right to patent within three months. Tekes requires that the participants in a project sign a consortium agreement. Enterprise projects are owned by companies which can also claim industrial ownership and can apply for patents. Usually, Tekes funds such projects only partly.[145]

Tekes, the Academy of Finland and their respective budget providing ministries show a clear science-technology divide. The Science and Technology Policy Council bridges the divide between the two ministries. The Prime Minister chairs this council which furthermore includes the Minister of Education and Science, the Minister of Trade and Industry, the Minister of Finance and zero to four other ministers. In addition, ten other members are appointed, including representatives from the Academy of Finland, Tekes, the universities, industry and employees. Although the council addresses both science and technology policy issues, its internal structure suggests that the science-technology divide is still in place, at least partly, because it has a science policy subcommittee, chaired by the Minister of Education and Science, and a technology policy subcommittee, chaired by the Minister of Trade and Industry. (Anonymous, s.a.-f)

6.3 A joint nanotechnology research program

The Nanotechnology Research Progam was the first in which Tekes and the Academy of Finland cooperated. Efficiency and ideas about the relation between basic and applied research and the role of research in society lead to cooperation. The two RFOs launched one program and both adjusted their funding criteria somewhat.

market." The main instrument is direct communicative interaction between Tekes's experts and customers. (Tekes, 2006, p. 8)

[145] Interview with M. Lämsä.

A start of collaboration

At least two reasons can be identified for the joint operation of the nanotechnology research program. Firstly, the Academy of Finland noted a change in science's societal legitimation and a change in the innovation process that researchers operate in. In the foreword of the 1996 Annual Report, president Vihko announced that Tekes and the Academy of Finland were developing increasingly more close cooperation through their programs. He continued:

> " Diversification of the innovation process presupposes increasingly close cooperation among researchers, representatives of technology, and business enterprises. The Academy of Finland expects that the coordination of the idea frameworks of the Academy and Tekes will lead to a widening of perspectives and to new opportunities in the development of scientific research, entrepreneurship, economy and employment in Finland" (p. 3)

In so many words, a blurring of boundaries was noted and hence a merging of perspectives seemed logical. Elsewhere in the Annual Report, the Academy noticed changes in "science and its societal status [which] have signified a lowering of conventional fences between various fields of science and between basic and applied research" (Academy of Finland, 1997, p. 7).

A second reason for a more close cooperation had to do with efficiency. When in 1995 the Academy of Finland was reorganized, J. Hattula became the new Director of Research. Hattula noticed a lack of cooperation between Tekes and the Academy of Finland. He had a division of labour between the two organizations in mind where Tekes would focus on applied research and the Academy of Finland on basic research. However, a research program or project could involve both types and then parties should agree on funding. Hattula felt that duplicate projects were a waste of resources. (Hietanen, 1995)

Developing the first program

The sketched developments at the Academy of Finland more or less coincided with a few other events. Within Tekes three technology experts, viz. O. Knuuttila, J. Vapaavuori and J. Kivikoski discussed the need for co-ordinated long term investments by Tekes and the Academy of Finland in emerging fields. Nanotechnology happened to be a personal interest of one of the three. Also, in the autumn of 1995, the European Commission organized an ESPRIT workshop 'long Term Research' in Finland[146]. The workshop's theme was 'future emerging

[146] ESPRIT is the European Strategic Program for R&D in Information Technologies, launched in the early 1980s. It was incorporated in the European Union's first Framework Program and had follow

technologies' and also dealt with nanotechnology and this further stimulated the idea of developing a nanotechnology program. At some point the people from Tekes connected to Hattula, J. Keinonen, member of the Research Council for Natural Sciences and Engineering, and others from the Academy of Finland. In addition, contacts were made with Finnish researchers. It all added up to the launch of the Nanotechnology Research Program in 1997. (Granqvist, 2007, p. 159 - 160) The field was, so to say, 'in the air'.

Here an intermingle of somewhat independent developments and events occurred. Kivikoski and his colleagues argued that because of Finland's small national budget, it could not catch up if other countries already had a head start. Nanotechnology however was just about to start, so they saw a chance for Finland. There were other programs and options. Biotechnology was an emerging field and food research came on the agenda as Finland joined the EU in 1995, which introduced the EU food regulations to Finland. Nanotechnology was picked as well, and as Kivikoski explained, with hindsight, they were right[147].

The Nanotechnology Research Programme

The Nanotechnology Research Programme was the first program that was planned and co-financed by the two RFOs. Tekes added FIM 25,6 M to the program's budget and the Academy of Finland FIM 18,3 M (Tekes 2000, Preface). The Academy of Finland funded its contribution through the running Materials Research and Structures Research Programme (MATRA). For this, the Board of the Academy of Finland increased MATRA's budget with FIM 15 M (Academy of Finland, 1997, p. 10). Although it was one program with investments from both organizations, the two used their own review procedures. Tekes used in-house experts, whereas the Academy of Finland used external reviewers[148]. The particular contributions of the two to each project were administered and specified in the evaluation report. Out of fourteen projects only two received funding from both funding organizations. Besides these, the Academy of Finland funded one project and Tekes nine[149]. (Yu & Ziegler, 2000)

Besides sharing the costs of the program, the cooperation between the Academy of Finland and Tekes within this program included the following. There was only one administrative location, which was housed by Tekes (Tekes 2000, p. 3). Tekes, however managed the program in a different way than it was used to. Instead of a full time program coordinator and a steering committee,

ups until and including the fourth Framework Program which ended in 1999. (Guzzetti, 1995, p. 76 - 82; Rogers, 1997)

[147] Interview with J. Kivikoski.

[148] Interview with J. Kivikoski.

[149] Of two projects, no information funding information is presented in by Yu & Ziegler (2000).

the nanotechnology program had a part time coordinator and no steering committee. (Yu & Ziegler, 2000, p. 1) At the Academy of Finland, the MATRA program board monitored the Nanotechnology Research Programme. Tekes attended the meetings of this board (Tekes 2000, p. 3).

Both Tekes and the Academy of Finland compromised on their funding criteria. Project proposals had to be of high scientific quality and economic potential, which meant an additional criterion for the Academy of Finland (Tekes 2000, Summary; Yu & Ziegler, 2000, p. 1 - 2). Tekes compromised by dropping the standard requirement of industry involvement and matching. The nanotechnology program was meant to be something new and if the criterion was applied then there would be no applications at all because Tekes figured that nanotechnology was too far ahead of what companies were doing[150]. Industry was however represented in the steering boards of a number of projects and in the program's annual seminars (Yu & Ziegler, 2000, p. 1 - 2).

The program's final report and evaluation report used the following description of nanotechnology: "the science and engineering of extremely small (~1-1000 nm) structures" (Tekes 2000, p. 3; Yu & Ziegler, 2000, p. 1) The definition of nanotechnology as used in the program was developed by Tekes in a practical way with input from Keinonen, who chaired the MATRA steering group. If the nanometer range was increased then the program would include micro technology, which Kivikoski and his colleagues did not want because they wanted something new. Secondly, the program required that a particular function of a material was addressed. If that were left out, then the entire field of chemistry would be part of nanotechnology, they argued.[151]

The program did not have a predetermined subdivision of nanotechnology. According to the program's final report because the funders wanted to be open to proposals from different disciplines. One stated motivation for the program indeed was a "desire to foster new, interdisciplinary interactions leading to new, unforeseen opportunities for creativity and innovation." (Tekes 2000, p. 3). Afterwards, five groups of projects were identified and briefly described. These were "nanobiology", "self-organizing structures", "functional nanoparticles", "nanoelectronics" and "biomaterials for information technology" (p. 4). Although this grouping was made, it seems to have had no further role or function in the program.

The program addressed the issue of societal demand for a more close connection between industry and public research in terms of the "enormous industrial potential foreseen for nanotechnology" (Tekes 2000, p. 3), which was forwarded as a main motivation to launch the program. A need was identified "to educate researchers equipped to explore new ideas in nanotechnology to

[150] Interview with J. Kivikoski.
[151] Interview with J. Kivikoski.

help realize this potential within Finland" (p. 3). These issues were taken seriously in the sense that in the program's evaluation report explicit attention is paid to each project's "Commercial Potential" and in the final report to "Capabilities Generated by the Project" and with a few projects also to "Generated patents" (Tekes 2000; Yu & Ziegler, 2000)

The program's final report concludes about this aim of commercial exploitation that "the programme could have managed better, in spite of the initial position, great risks and the exploratory nature of research have been taken into account." (Tekes 2000, p. 5). The report suggested that in future programs, project groups should carefully plan utilization plans and try to involve industry from the start. The report continued that in Finland "much needs to be done to develop mechanisms by which research results are converted into business" (p. 5). To put this in perspective, the report added that all over the world, industry was still at the "embryo stage" and nanotechnology still in the "pre-competitive phase".

The program used project funding exclusively and had no particular budget reservations for facilities or equipment. The evaluation report concluded that the scientific quality of the projects ranged from quite good to state of the art. These state of the art projects "benefited from a highly developed research infrastructure, that had been established previously" (Yu & Ziegler, 2000, p. 3). Although, it is not clear what is meant with infrastructure, which may also include for example education and research capacity, this could indicate that facilities and their funding were already in place and needed no additional funding.

The projects of the Nanotechnology Research Programme finished in the course of 1999 and in September all projects presented at a workshop for the evaluation of the program. Regarding the scientific quality the projects were evaluated as quite good or close to or at state of the art. When it came to commercial impact, the evaluation report saw a few instances of success. The program's final report was less optimistic, but pointed out that it was too early to expect more. The field was considered to be in an early phase and industry not ready yet, it suggested. The report was dated April 2000 and its summary referred to then United States' president Clinton's plans to invest substantially in nanotechnology as of 2001 and its conclusions more or less warned Finland: "It is not believed that Finland can simply afford to stay outside while the rest of the world is increasing investments in nanotechnology." (Tekes 2000, p. 6)

Around April 2000, Tekes nor the Academy of Finland intended to launch a follow up program. In case of the Academy of Finland, this probably was the regular way of working. In the 1990s and beginning of the next decade, most programs had no regular follow up programs and a few programs were extended with a year or more. The Nanotechnology Research Program was located within the Materials Research and Structures Research program and this lasted until 2000.

6.4 FinNano at Tekes

At Tekes, the program was not continued because it was felt that it was not needed to stimulate nanotechnology as such anymore. It was noted that interest among companies increased after the program[152]. After the program ended, the Tekes officials who had worked on the Nanotechnology research program, viz. Kivikoski and Oiva Knuuttila, did launch a discussion group together with two others[153]. The group kept track of nanotechnology developments and discussed them about four to five times per year.

In the course of 2002, M. Lämsä was hired at Tekes. Lämsä, who holds a PhD in supramolecular chemistry, joined the group and one of his first jobs was to do the keeping track of nanotechnology: of the nanotechnology projects within Tekes[154], of the companies that were active in the field, and of what else happened in Finland and abroad. Also in 2002, the group organized a two week trip for twenty persons in all to Japan and the USA. The group consisted of researchers from Finnish universities, research institutes, representatives from companies, Tekes, and the Academy of Finland. They met high profile researchers in nanotechnology and learned that both countries invested substantial amounts, mainly in buildings and infrastructure.[155]

In 2002 and 2003 a big issue of discussion within the group was whether or not a new nanotechnology program should be launched. The group was not sure what the added value of a program would be. It reasoned that Finland is a small country and all its professors were identified, all companies were identified and all these actors knew of each others' existence.[156]

At some point in 2003, something had changed and through Tekes' internal mechanisms to develop many ideas ideas into a selected set of programs, Tekes' second nanotechnology program emerged.

[152] Interview with J. Kivikoski.
[153] Interview with M. Lämsä.
[154] Although there was no special nanotechnology program, projects dealing with nanotechnology were funded through other programs.
[155] Interview with M. Lämsä.
[156] Interview with M. Lämsä.

Developing a program at Tekes

In 2003 Kivikoski, who then was one of the two directors for the department of Bio- and Chemical Technology, asked Lämsä to develop a proposal for a nanotechnology program. This was part of normal operating procedures within Tekes. Internally, all staff collects 'seeds' or 'seed ideas' for new technology programs continuously. If such a seed idea sounds like a promising idea, one may receive working time and a few resources to write a compact proposal of a few pages. If that proposal is accepted one is allowed to work out a proposal for for example a policy focus area or a technology program. In that case one may receive budget to organize workshops or seminars, or to commission a survey or study. Such a proposal may then be presented to Tekes's Board for approval.[157]

Most seed ideas do not make it to the end of this step-wise process and there is a kind of competition between Tekes officials. Ideas have to be made appealing to higher ranks. They have to be made attractively new, but at the same time they have to connect to existing Tekes policy and government policy.[158]

Lämsä received a budget of about € 140 K to develop a proposal for a nanotechnology program. A team was put together consisting of the discussion group plus a person from Tekes's communications department and a person from the international collaborations department.[159]

In 2004, Tekes commissioned a new consultancy firm called Spinverse to survey which companies in Finland worked on nanotechnology. Spinverse held a number of interviews and identified about sixty five companies. It also drew up a list of strong points of Finnish nanotechnology[160].

After Lämsä had finished the draft proposal in the summer of 2004, he organized a seminar to present it to around three hundred fifty researchers and representatives of all organizations involved. The Tekes Board approved the proposal and in December 2004, Tekes announced the first call for pre-proposals. The first funding decisions were made in the first months of 2006[161].

The Tekes FinNano program

The Tekes Board approved the nanotechnology program and the first call was launched in December 2005. The program will run until the end of 2009 and has a budget of about € 45 M. Of this budget, € 25 M is available for Research

[157] Interview with M. Lämsä.
[158] Interview with M. Lämsä.
[159] Interview with M. Lämsä.
[160] Interview with M. Lämsä.
[161] Interview with M. Lämsä.

projects and € 20 M for Enterprise projects and loans. In addition to the € 45 M companies are expected to match about € 20 M. By the end of 2007 there were about fifty running projects. (Tekes, s.a.)

The program's website offers a description and a definition of nanotechnology which are not exactly the same. The program description page:

> "Nanotechnology refers to science and technology operating at atomic, molecular and macromolecular levels and where the distances stretch from one nanometre to a hundred nanometres. Nanotechnology is an enabling technology and is connected to several different sectors. The point of departure is genuinely multidisciplinary, i.e., a combination of physics, chemistry and biology and engineering sciences." (Tekes, s.a.)

The definition page

> "Nanotechnology refers to science and technology operating at the level of atoms and molecules, i.e., in the nano size class, as well as scientific phenomena and new characteristics which one can learn to understand when operating at this level. These characteristics can then be observed and utilised in the micro- and macro size class.
> One nanometre is a billionth part of a metre (1 nm = 10-9 = 0.000000001 m). The building units of nanoscale matter are on a critical scale - typically below 100 nm, which means that the quantal and thermodynamic characteristics of the materials become dominant.
> Nanotechnology is horizontal and enabling, because it can have effects in practice in all branches of technology. Nanotechnology often combines numerous branches of science and harnesses multidisciplinary approaches that bring different sciences closer together. It is also a disruptive technology because it can be used and applied in several different applications." (Anonymous, s.a.-c)

Tekes used this comparatively broad definition on purpose. At Tekes, it was argued that taking a more precise definition would push the program towards basic science and companies are not interested in that but have a particular need for their product development. Nanotechnology is just one element in this.[162]

Still the program did highlight a few boundaries for the projects to be eligible for funding. The scale should range from 1 to 100 nm and the functionality aspect of the researched matter had to be addressed. In particular, a specific functionality had to be planned or aimed for so that the projects would be about technology development. Tekes does not use the number of dimensions to which the nanoscale should apply as a criterion because it does not want to restrict applications too much.[163]

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[162] Interview with M. Lämsä.
[163] Interview with M. Lämsä.

The program focusses on three areas within nanotechnology, viz. "Innovative nanostructure materials", "Nanosensors and nanoactuators", and "New nanoelectronics solutions" (Tekes, s.a.). Developing this list, was a particular problem that the program team had to solve. Finland, being a small country, could not invest in all areas of nanotechnology, like the United States or Japan could. So, it argued, only a few areas could be addressed in Finland. Unfortunately, a chemists would propose nano chemistry, a researcher in information technology would propose nano electronics and so on. Based on its overview over all nanotechnology parties and activities in Finland, and taking developments abroad, including the EU action plan into account, the team selected materials research, electronics, and sensors and actuators[164].

When it comes to technology transfer and promoting economic development, the FinNano program at Tekes has no additional activities apart from the Research projects, Enterprise projects and loans to companies. It pays no attention to facility and equipment funding.

Explicit program aims are to "render the economic exploitation of research data more effective by converting research results into technology and products and to strengthen and accelerate the commercial development of nanotechnology" (Tekes, s.a.) and to "encourage enterprises to see the potential of nanotechnology, and ensure that there emerge good prerequisites for utilizing nanotechnology applications" (Tekes, s.a.). The program focused on existing companies. It turned out that the number of companies active in nanotechnology has grown from the sixty four that were identified by Spinverse to around one hundred thirty as tracked by Tekes until the end of 2008.[165]

Tekes outsources the administration of FinNano to a consultancy firm and monitors projects closely through site visits and meetings. It sets aside budget for program coordination so that besides outsourcing program coordination, it can also fund activities as program workshops and seminars, exhibitions or excursions abroad.[166]

6.5 FinNano at the Academy of Finland

The Academy of Finland started developing a nanotechnology program before Tekes did, but launched it somewhat later. This had to do with the Board's procedures to develop a program. Being a representative body of the Research Council, it may take time before a program proposal has enough support.

[164] Interview with M. Lämsä.
[165] Interview with M. Lämsä.
[166] Interview with M. Lämsä.

Another effect is that the Board is likely to adopt interdisciplinary programs. At least it did when it launched its nanotechnology program, which deviates from other programs in that it developed a nanotechnology driven division of the field instead of a division based on existing disciplines or existing strong national fields of research.

At one point in time, Tekes and the Academy of Finland decided to cooperate with their respective programs. It was not planned in advance. Both had their own procedures to identify and launch a program. The field of nanotechnology was not the trigger for cooperation, but internal pressure for more efficiency and external pressure for a closer cooperation from the Government.

Developing a new program at the Academy of Finland

At the Academy of Finland, the regular procedure that leads to commencing of a research program is a step wise one. In principle everybody is free to propose a program to a Research Council within the Academy of Finland. If the Board adopts the proposal it will then start to discuss it and negotiate about it with the other Research Councils in order to gain support in the Board of the Academy of Finland. More than half of the Board members are the chairs of the Research Councils[167], so it makes sense to gain their support. In most cases, a proposal starts with a rather focussed program, but through the discussions between the councils it is broadened. Then the proposal is presented to the Board and adopted or not.

In principle different types of actors can propose programs to the Board. Researchers can turn directly to the Board with their program proposals, but this hardly ever happens[168]. Also, ministries and companies can propose as well and sometime ministries do, but the Board is independent and can decline if it wants to. The Board can also itself develop a program and this happens in about one out of ten cases.[169]

The normal bottom up procedure was also more or less followed in case of a new nanotechnology program of Academy of Finland, which later became known as FinNano. The Research Council for Natural Sciences and Engineering developed an idea for a nanotechnology program in 2002 through bottom up procedures in which researchers and Council members participated[170]. In December 2003, the Board allowed the Research Council to start negotiations about a "research programme on chemical, physical and biological nanosciences" which was planned to start in 2006 (Academy of Finland, 2004, p. 26). The list of disciplines does not mention Health, but at some point

[167] The Board consists of a chair, the chairs of the Research Councils, a representative from research organizations and a representative from industry.
[168] Interview with K. Väänänen.
[169] Interview with E. Heikkinen and P. Kauppinen. Interview with K. Väänänen.
[170] Interview with P. Ahonen.

K. Väänänen[171] contacted the group that was developing the program and suggested that a representative of the Research Council for Health was included as well to address the issue of potential health risks of nanotechnology[172]. Besides other Research Councils, the Research Council for Natural Sciences and Engineering involved funding organizations from Finland and abroad, and representatives from industry and business in the development of the program. In April 2004 an exploratory workshop was held. (Academy of Finland, 2005a, p. 28; 2005b, p. 36)

Half a year after the workshop, the President of the Academy of Finland launched a program preparation group. This group consisted of a chair and representatives of the Research Councils for Natural Sciences and Engineering, Biosciences and Environment, and Health. The group together with program manager P. Ahonen discussed which professors should be added to the group based on the group's knowledge of who the important researchers in Finland are[173]. (Academy of Finland, 2005b, p. 36) M. Lämsä was also invited and joined the group[174].

In November 2005, the Board approved the launch of five new research programs, amongst which the Nanosciences Research Programme. The Board had allocated € 9 M from the 2006 budget for the program, which made it the biggest of the five. The other four received between € 5,5 M and € 7,5 M[175]. In total € 36 M was allocated to the programs. To provide some more contrast to the investment: in 2006 the Academy of Finland spent about € 239 M in all, including the € 36 M for the new research programs. (Academy of Finland, 2007b, p. 22; Tanner, 2005)

FinNano program of the Academy of Finland

The Academy of Finland's FinNano program is planned to last from 2006 until 2010 and to spend € 9 M in total. The program funds research projects of consortia of two or more research groups. Funding is available for postdoctoral researchers and doctoral students, research costs, travel expenses, meetings and support of research mobility. No particular budgets are available for equipment or facilities. (Academy of Finland, 2005b, p. 43 - 45)

[171] Väänänen became Chair of the Research Council for Health in 2004.
[172] Interview with K. Väänänen.
Possibly, this happened in 2005 (Academy of Finland, 2006, p. 31).
[173] Interview with P. Ahonen.
[174] Interview with P. Ahonen.
[175] The others were Sustainable production and Products (€ 7,5 M), Nutrition, food and Health (€ 7 M), Power in Finland (€ 7 M) and Substance Abuse and Addiction (€ 5,5 M).

The brochure's[176] subtitle reads "research program on nanoscience (finnano) 2006-2010)", and the brochure describes nanoscience as follows:

> "Nanoscience is targeted at studying the nanoscale, atomic or molecular level, systems and related phenomena. The phenomena and objects under investigation must be novel, which claims that merely a small size is not a sufficient parameter. The approach in this research programme must be interdisciplinary." (Academy of Finland, 2005b, p. 35)

Remarkably, compared to most other definitions or descriptions of nanoscience and nanotechnology, this program does not define the range of nanometers, at least not in this generic description of the field. Only in the description of one of the three thematic areas the range of nanometers is mentioned as a characteristic of the area.

The program made a distinction between nanoscience and nanotechnology: "Nanotechnology, on the other hand, can be considered to include applied nanoscience together with exploitation." (p. 35) The program objectives made clear that the program focussed on nanoscience, not on nanotechnology. Nanotechnology was mentioned only by the aim to "advance responsible development of nanotechnolgy" (p. 37) which meant that the program would take ethical challenges such as safety, health and environmental issues into account.

The need for and relevance of a nanoscience research program was described mostly in terms of scientific relevance and secondly in terms of economic relevance. The first and second line of the introduction of the program brochure read "Science is focusing more and more on nanoscale phenomena and structures, and there is need for increased research and better control of them. Scientific curiosity is an important driver in this, but there are also visions for such possible new products and services that may bring sustainable development and competitiveness in the community." (Academy of Finland, 2005b, p. 35) A few paragraphs later, the program brochure mentioned that "In many national strategies, nanoscience and nanotechnology have been brought up because of their economic potential." (p. 35) which suggests that the fact that other countries invest is more important then the economic potential. At least, the brochure itself does not claim that there is economic potential for Finland in nanotechnology.

Accordingly, the review criteria of project proposals do not pay much attention to economic potential of the proposal. A "justification for why the research project is relevant to the nanoscience research program and with which program theme areas the research ties in" (p. 43) is required, and the "scientific quality and innovativeness of the research plan" (p. 44) but no analogue criteria for industrial or economic justification, quality or innovativeness were asked

[176] The brochure contains the program's description in Finnish, Swedish and English. Each language part consists of fifteen to twenty pages. Here only the English part is discussed.

for. Out of dozens of requirements and required annexes such as research topic and objectives, the research plan, the objectives and methods, composition of the research groups and background of the researchers, that applicants had to provide in the course of the application, only the "practical applicability of research results" (p. 45) must be indicated under 'results' in final research plan. Not the economic/industrial applicability should be indicated, but the practical applicability, which in my view may include economic/industrial applicability. I do not mean to suggest that the Academy of Finland made a mistake here, but I wanted to illustrate that the issue of nanotechnology's economic potential is simply not explicitly addressed by this program and its brochure.

When the program's thematic areas are discussed, the brochure makes clear that although "It is very hard unambiguously to define nanoscience ..." the program prescribes that projects "should be focused on novel properties and functions. Traditional research on chemistry, physics and life sciences, as such, does not fulfil the characteristics of nanoscience." (Academy of Finland, 2005b, p. 38) So, the program connects the aspect of new phenomena and the study thereof to nanoscience's interdisciplinary character.

The program's subdivision in areas also explicitly tries not to use known categories: "the starting point [of developing the program and selection of proposals] was/is genuinely interdisciplinary research. Therefore, a research project should not be built on a single discipline or engineering point of view. ... As the thematic areas were chosen, care was taken in not to target at any specific discipline or research ares, but rather keep themes generic and relevant to several areas." (p. 38)

And indeed, the list of areas was not similar to for example nanomaterials, nanoelectronics and bionano, but 'Directed self-assembly', 'Functionality in nanoscience', and 'Properties of single nanoscale objects'. The program adds an additional step which makes clear that it aims for interdisciplinary research and tries to prevent the regular subdivisions of nanoscience. Each of the themes is described with a few paragraphs and a list of themes that could be addressed within the area. Within each of the three lists electronics related themes occur: the area of Directed self-assembly lists the theme 'Self-assembly with lithography and electronics', the area of Functionality in nanoscience lists 'Bionanotechnology for electronics and materials science', and the area of Properties of single nanoscale objects lists 'Nanoscale circuitry, mechanics, actuators and photoactive systems' and 'Molecular data storage and machines'. Similarly, all areas list materials related themes and two list bio related themes. (Academy of Finland, 2005b, p. 38 - 39)

As with other programs, the Academy of Finland tried to realize interdisciplinary research in its FinNano program[177], not only by structuring it in an interdisciplinary way, but also by setting up the Programme Steering

[177] Interview with P. Ahonen.

Group in an interdisciplinary way. It consists of a chair (from the Research Council for Natural Sciences and Engineering), a vice chair (from the Research Council for Biosciences and Environment) and representatives from three Research Councils (viz. Natural Sciences and Engineering, Biosciences and Environment, and Health), Tekes, The Ministry of Education, Orion Pharma and VTT Processses. (Academy of Finland, 2005b, p. 41)

Secondly, the program requires that applicants organize themselves in consortia of two or more research groups. This is not a standard requirement of the Academy's programs. In case of the FinNano program, the program managers were surprised to see the size of the consortia that handed in proposals. Some comprised eight research groups and according to a former program manager, the funded proposals indeed show that researchers from different disciplines are participating and supporting each other cross disciplinary.[178]

Finally, as of 2006, the Academy of Finland installed a Program Unit in its organization which is responsible for administration and coordination of the programs. It is an administrative body. In terms of scientific management, the program boards and the Board of the Academy of Finland remain responsible. Before the introduction of the Program Unit, the Research Councils were responsible for coordination and administration of the programs. The Program Unit exists next to the Research Councils' units and hence sits at a location outside the disciplinary divisional structure.

The FinNano program was launched through a call for 'plans of intent' on December 30th 2005. Consortia of researchers were invited to hand in plans of four pages or less before the first of February of the following year. This resulted in about one hundred proposals which were reviewed by the Program Steering Group. The group rejected about half of the proposals[179] and the applicants of the other half were invited to send in full applications before the end of April 2006. The full applications were reviewed by an international expert panel and scored on a scale of one to five. Based on the findings of the panel and "bearing in mind the objectives set for the programme" (Academy of Finland, 2005b, p. 40) the Program Steering Group would propose a list of projects to fund to the Program Subcommittee.

The phrase "bearing in mind the objectives set for the programme" suggests that the Program Steering Group has discretionary power to deviate from the review panel's findings. And as one of the group members indicated, this possibility indeed exists: if a program board, such as the Program Steering Committee, wants to stimulate a particular area, but there are no project proposals with the maximum score that address it, then the board may decide

[178] Interview with P. Ahonen.
[179] Interview with K. Väänänen.

to prioritize projects with a less than high score. This however hardly ever happens.[180]

In August 2006, funding decisions were made covering eight consortia with a total of forty six research projects. A few months later, the Academy of Finland decided to fund two additional consortia with seven projects and the Finnish participation in the NanoSci-ERA[181] program of the FinNano program (Academy of Finland, 2007a). The program, like the Tekes FinNano program, does not have a special budget set aside for facilities and equipment.

Program management and monitoring consists of progress reports to the Program Steering Group and seminars for post docs and PhDs to provide them with a broader perspective on the projects they work on and to make them aware of issues such as research ethics and innovation systems[182]. The first was held in April 2008 in cooperation with Tekes and the second in September 2008.

Cooperation through FinNano between the Academy of Finland and Tekes

In 2005, probably towards the end of 2005[183], the Academy of Finland started to use the name FinNano for its nanotechnology program. Tekes had been using the name as of its 2004 annual report, published in March 2005. So, at some point in 2005 the two funding organizations decided to stress their cooperation on their nanotechnology programs by using the same name.

Besides adopting the FinNano name, the two RFOs keep each other informed about the applications they receive in order to prevent duplicate funding. Secondly, the two programs inform each other about their activities and forward this information through their respective networks. Moreover, researchers from the programs are mutually invited for program activities. In April 2008, the first common seminar was held. Thirdly, international visibility also is a common cause. Tekes and the Academy of Finland cooperatively receive international delegations with an interest in nanotechnology. Finally, a program manager of the Academy of Finland's FinNano program takes a seat in the Tekes FinNano program board and vice versa. The Academy of Finland's program manager also played a role in Tekes's FinNano proposal review.[184]

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[180] Interview with K. Väänänen.

[181] This is a joint program of funding organizations under the ERA net scheme of the Sixth Framework program of the European Union. For more information see http://www.nanoscience-europe.org/ and (European Commission, s.a.-b)

[182] Interview with P. Ahonen.

[183] The Academy of Finland's annual reports until and including the 2004 report (published in 2005) do not use the FinNano name. Nor does the November 2005 press release which announced the investment decision. The program brochure which is dated 2005 does use the FinNano name.

[184] Interview with P. Ahonen. Interview with M. Lämsä.

On the latter issue, vice versa does not occur because the Academy of Finland uses external researchers for proposal review.

The cooperation of Tekes and the Academy of Finland was not a one-of event. The two cooperate through financial participation on other programs, and on other funding instruments as well. In addition, the two took shared responsibility in for example the national coordination of the preparations for the sixth European Framework Program and a recent foresight study.

Interviewees from both funding organizations admit that the cooperation could be increased, for example through operating one nano research program. They are however perfectly comfortable with not doing this. Basically, they acknowledge that practices in the other organization are different from their own and that they differ for good reasons related to their respective tasks, viz. basic research and applied research funding.

At least two reasons for cooperation are mentioned. The first is the same drive for more efficiency that also underpinned the 1997-1999 nanotechnology program. Actors want to prevent that researchers can apply at both funding organizations for the same project. If researchers could do so, than that would be strange in view of the division of tasks between Tekes and the Academy of Finland. Therefore Tekes and the Academy of Finland had been checking for double applications already before the FinNano program.[185]

The second reason is that there is an ongoing debate about the division of tasks between Tekes and the Academy of Finland[186]. Top management of the two RFOs and other organizations stress the importance of cooperation and want to increase their efforts (Georghiou et al., 2003 p. 82). Georghiou's interviewees saw increasingly more justification for more cooperation in the fact that it had become less easy to draw borders between basic research and applied research. A few years later, the RFOs came/remained under pressure when Government announced increased collaboration between them and between them and private and foreign funders (Council of State, 2005; Pelkonen et al., 2008).

K. Väänänen, the current chair of the Research Council for Health, however notes that at present, the policy debate is pushing all research funding towards applied research funding. He argues for a protection of basic research and points out that Tekes simply was not interested in investigating side effects of nanotechnology to human and animal health.[187]

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[185] Interview with E. Heikkinen and P. Kauppinen.

[186] Interview with K. Väänänen.

[187] Interview with K. Väänänen.
See also Academy of Finland (2007b, p. 14)

6.6 Ministerial support for nanotechnology equipment

In all three nanotechnology programs discussed in the preceding sections, no particular attention was paid to nanotechnology's claim to high budgets for equipment and laboratory facilities. This is a result of a general policy that infrastructure is paid through the universities' budgets. The Academy of Finland does not make reservations for investments within funding programs, not for nanotechnology, not for any other theme. The Academy of Finland however has had two or more investment programs. However, it is not happy with this situation, because, as one interviewee pointed out, it draws money away from actual research funding. By the end of 2007, the Ministry of Education was surveying the use of existing infrastructure in order to develop a more structural policy. One suggestion was made to establish a Research Council for infrastructure.[188]

Some groups are successful at funding programs of both Tekes and the Academy of Finland. Some laboratories also receive money from companies. Universities and institutes try to manage different sources and combine incomes to finance big investments in equipment and laboratories.[189]

The universities did discuss the field of nanotechnology with the Ministry of Education and suggested that the Ministry made funds available for investments. The universities used regular channels for these suggestions and the Ministry, while involving the RFOs, was open to them. This section accounts the story.

Investments for equipment and enrollment of the RFOs

In or around 2004, the University of Jyväskylä, the Helsinki University of Technology and VTT (Finland technological research institute) suggested that the Ministry gave more attention to nanotechnology. Because both the Academy of Finland and Tekes had at that time been working on their respective programs for nanotechnology and through this had been coordinating the field, the Ministry had to take a broader perspective to see what it could add. The Ministry erected a working group which was to survey the current activities in the field of nanotechnology in Finland and identify the most developed research agendas to fund. Also, the Ministry made € 24 M available, which is much more than usual for Ministerial development programs.[190]

[188] Interview with P. Ahonen. Interview with E. Heikkinen and P. Kauppinen. Interview with K. Väänänen.
[189] Interview with P. Ahonen.
[190] Interview with P. Ahonen. Interview with E. Heikkinen and P. Kauppinen.

The working group included representatives of the University of Jyväskylä and of the Technical University of Helsinki, Tekes (M. Lämsä) the Academy of Finland (P. Ahonen), VTT and CSC (a company without profit aim that belongs to the Ministry and that, among other things, functions as an academic computing centre). Finally a small number of professors were invited, based on an educated guess of where to find the most important centers for nanotechnology in Finland.[191]

The Ministry's policy makers actually did not want to discuss the definition of nanotechnology during the first meetings of the working group because it was expected that there would be as many ideas as there were members of the working group. The group agreed that not only the nanometer scale should count, but also the functionality of matter at that scale. This was in line with what Tekes wanted and the Academy of Finland followed Tekes here. The criterion of functionality would then also link the Ministry's funding policy to those of the two funding organizations. The working group did not develop a subdivision of nanotechnology because it wanted to be flexible towards the subdivisions of the two FinNano programs.[192]

The working group decided to fund gaps in the funding decisions of Tekes and the Academy of Finland and secondly to strengthen what the two already supported so that the universities would have all the funds they required for their nanotechnology research. Research proposals were evaluated by the two representatives of the Academy of Finland and Tekes. This strategy boiled down to support for the University of Jyväskylä, the University of Tampere and the universities in the greater Helsinki region which comprises the University of Helsinki and the Helsinki University of Technology.[193]

During the spring meetings of 2006, the Ministry allocated € 21 M of the available budget to acquisition of a transmission electron microscope and other equipment. It made sure that the equipment would be available to other institutes and universities as well.[194]

This short story illustrates how the regular contacts between the Ministry of Education and the universities are used to fill the funding gap of expensive equipment and facilities.

The working group proposed to launch a Nano forum which should develop future visions on nanotechnology for the funding organizations. Secondly, the forum should develop a way to evaluate the effects of the Ministry's nano funding activities. The Ministry of Education followed up on this and invited all the other twelve Ministries to participate in the forum. The Ministry of Social

[191] Interview with E. Heikkinen and P. Kauppinen.
[192] Interview with E. Heikkinen and P. Kauppinen.
[193] (Academy of Finland, 2005b)
Interview with E. Heikkinen and P. Kauppinen.
[194] Interview with E. Heikkinen and P. Kauppinen.

Affairs and Health, The Ministry of Trade & Industry, the Ministry of Foreign Affairs, the Ministry of Environmental Issues and the Ministry of Agriculture responded to the call. Besides the representatives from these ministries and the Ministry of Education, the FinNano program managers represented the Academy of Finland and Tekes respectively. Until October 2007, the forum had held two meetings. During the first the representatives introduced themselves and their ministries' interests in nanotechnology. The second meeting was a site visit to the University of Jyväskylä's nanotechnology center.[195]

6.7 Conclusion: Living apart together

There were two reasons for selecting Finland as a case for this thesis. One was that the cooperation between the science RFO and the technology RFO on two occasions involving nanotechnology programs seemed to indicate that the two RFOs tried to bridge the science-technology divide. Such attempts to bridge the divide may be telling with regard to the issue of society's changing demands regarding the relation between science and industry. Because most definitions of nanotechnology stress its appeal to both basic science and technology development, the cooperation between the two RFOs could be telling about RFO's adaptations to an new emerging field.

Perhaps the most important conclusion is that the cooperation between the two RFOs was not triggered by the emerging new field, but by external pressure to cooperate more closely. In that respect, nanotechnology was an exemplar, in 1997 perhaps a kind of testbed because it was the first joint program and in 2005 FinNano was another opportunity, just like other programs were.

The second most important conclusion is that cooperation was more about keeping the science-technology divide in place than about bridging it or blurring the boundary. Perhaps the most illuminating illustration of this is that whereas the first cooperation resulted in a joint program, the second cooperation was shaped as two separate programs that were developed independently of each other. Most cooperation took place after the parallel programs were developed (See Table 4).

Thirdly, the chapter also explains or at least makes understandable why a deeper cooperation is unlikely: the two organizations have different resource dependencies to actors in their environment, their respective environment enactment processes are organized differently, and response selection and development operate differently (See Table 5, p. 126). Arguably, their

[195] Interview with E. Heikkinen and P. Kauppinen.

cooperation was more about articulating differences so that the two could stand more closely together, leaving as little funding 'twilight zone' between them as possible, than about developing a new approach towards a the new field of nanotechnology.

Fourthly, the resulting programs, in particular the two FinNano programs show signs of each RFO's business-as-usual approach towards the new field.

Finally, and this is not a conclusion but rather a comment, the two so to say 'happily co-exist' and go as far as they can in their cooperation considering their differences. In addition, the Ministries on both sides of the divide involve representatives from both sides of the divide while dealing with nanotechnology policy issues, for example where equipment funding is discussed.

Table 4: Different ways of cooperation on nanotechnology of Tekes and the Academy of Finland

Nanotechnology Research Programme 1997-1999	**FinNano 2005 - 2010**
One shared program	One shared name
One shared definition	Two definitions
Common program coordination	Separate program management
Mutual compromising of review criteria	Separate sets of review criteria
Common annual seminars	Common annual seminars
Excluding double funding of projects	Excluding double funding of projects
Information exchange between the two RFOs	Information exchange between the two RFOs
Mutual cross representation	Mutual cross representation
(Researchers participate in one program)	Informing researchers about activities of the other FinNano program
	Common representation in international contacts

Table 5: Differences between Tekes and the Academy of Finland in their FinNano programs

Aspect	Academy of Finland	Tekes
Environment enactment. (keeping track of changes in environment)	• Through academic boards and committees	• Through in house experts and discussion groups
Program selection and development	Bottom up, starting at research level	Bottom up, starting at in house staff
Review process	External peer review	In house experts' review
Program definition of nanotechnology/ science	• range of nanoscale not specified • investigation of novel phenomena and objects	• 1 to 100 nm • planned development
Relation between science and technology	Nanotechnology is different from nanoscience	Nanotechnology includes science and technology
Subdivision of nanotechnology	Based on creation of interdisciplinary topics: • Directed self-assembly • Functionality in nanoscience • Properties of single nanoscale objects	Based on analysis of actors in Finland: • Innovative nanostructure materials • Nanosensors and nanoactators • New nanoelectronics solutions
Program management	• Program steering group + Program subcommittee • In house program coordinator • Relatively loose monitoring	• Program steering group • Program manager at Tekes • Relatively close monitoring
Program administration	• In house administration	• Delegated to consultancy firm
Coordination activities	• workshops and seminars • comparatively small budget	• workshops and seminars • excursions abroad • comparatively large budget

6.8 Figures of the Finnish case

Table 6: Overview of incomes and budgets of Finnish RFOs and nanotechnology programs (x 1 000 000)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	FIM	FIM	FIM	FIM	FIM	FIM	FIM	FIM	FIM	FIM
Academy of Finland										
• Income from State[196]	-	-	-	-	490	458	502	824	850	925
• Funding decisions[197]	-	-	-	-	531	489	502	794	836	988
Nanotechnology research program[198]								18		
Tekes										
• Income from State[199]	-	-	-	-	1410	1564	1464	1168	2165	2445
• Funding decisions	-	-	-	-	-	-	-	-	-	-
Nanotechnology research program[200]								26		

Continued on next page.

196 Source: Academy of Finland annual reports 1994 - 2007.
197 Source: Academy of Finland annual reports 1994 - 2007. Excluding operational costs.
198 Source: Tekes (2000, preface)
199 Source: Academy of Finland annual reports 1994 - 2007.
200 Source: Tekes (2000, preface)

Table 6 continued

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	€[201]	€	€	€	€	€	€	€	€	€
Academy of Finland										
• Income from State[202]	154	185	185	185	214	223	259	276	297	
• Funding decisions[203]	157	184	177	184	208	219	239	264	287	-
• FinNano							9[204]			
Tekes										
• Income from State[205]	394	400	399	399	433	448	480	504	526	
• Funding decisions[206]	373	387	381	392	409	429	465	469	-	-
• FinNano[207]							45			

[201] In 2000/2001 € 1 equalled FIM 5.95
[202] Source: Academy of Finland annual reports 1994 - 2007.
[203] Source: Academy of Finland annual reports 1994 - 2007. Excluding operational costs.
[204] The € 9 M covers the program period until and including 2010
[205] Source: Academy of Finland annual reports 1994 - 2007.
[206] Source: Tekes annual reports 2000 - 2008. Excluding operational costs.
[207] Source: Tekes (s.a.)

7 The Netherlands: by-passing the RFOs

7.1 Introduction

In the Netherlands, nanotechnology saw a gradual increase in interest during the second half of the 1990s. A number of foresight organizations and advisory councils noticed the field in their reports and two divisions of the science RFO, which is called NWO, started financing nanotechnology programs, based on bottom-up proposal processes. In 2000, a third division made nanotechnology a priority area in its strategic plan. This triggered a response from the others and nanotechnology became a joint priority in NWO's new four year strategy plan which was published in September 2001.

Although it was a priority, in terms of financial commitment it was the smallest of its priority themes and plans for nanotechnology still had to be developed. Attempts to do so initially failed and were bypassed by other actors even before the strategy plan was published.

Around 1996, three groups of researchers from Delft, Twente and Groningen, each with its own laboratory, deliberately oriented their research interests towards nanotechnology. They attempted to scale up investments through a collaborative program proposal at a joint program of the Ministry of Education, Culture and Science and NWO. Their proposal was rejected, in part because their collaboration was too young. Their collaboration however continued and they kept up their efforts to acquire funding from government, which is how they became involved in a major Government research funding program.

In the early 1990s, the Dutch Government decided to spend part of an investment fund in research infrastructure. After two rounds in which it spent Fl. 250 M and € 211 M respectively, the Government invested € 800 M in the third round, known under the acronyms BSIK or ICES/KIS 3. An inter ministerial committee started preparations in 1998 and at the end of 2000, it identified nanotechnology as one of eight themes for funding. In the summer of 2001, a theme proposal had been developed by the group of three, researchers from a number of other universities, and a task force set up by the organizing committee. Later, the researchers developed a program proposal, titled NanoNed, which at the end of 2003, received about € 95 M funding for a five year period.

This was a huge amount compared to the € 3 M that FOM, NWO's division for physics, spent on nanotechnology in 2002. The division for Chemical Sciences spent a smaller amount. Thus NanoNed caused a change in the distribution of resources that governed the RFO's intermediary position in the field. For nanotechnology, researchers could turn to Government directly. FOM decided to come into action. In October 2004 it published its strategy plan for the next six years in which it adopted nanotechnology as a new priority. FOM pointed out that NanoNed was an application oriented program and that there was a need for a complementary basic research program. A few months later, FOM and STW, which is NWO's division for technology development funding, furthered their efforts by launching the Blank committee, named after the committee's chair. It developed a 'national nanoscience programme', which ended up in NWO's next strategy plan, published in May 2006.

In the course of that year, NanoNed, FOM, STW and two other NWO divisions teamed up to form the Netherlands Nano Initiative (NNI) and in the autumn, the Dutch Government published a White Paper on nanotechnology in which it encouraged the NNI to develop a national research agenda. For NanoNed, it opened an avenue for follow-up funding. For FOM and STW, it offered a venue to play a role again in Dutch research policy making for nanotechnology. NNI developed a national research agenda in the course of 2007 and 2008, based on the work of the Blank committee and extended with input from the White Paper and from workshops organized by NNI. The Dutch government meanwhile developed plans for a fourth ICES/KIS round. In June 2009, no funding decisions have been made regarding NNI's plans.

This outline of this chapter's story shows a number of closely related things. First it illustrates that developing priorities in a national setting of RFOs, research performers and government is a dynamic process. Secondly, in this process the RFO's intermediary position is not a given: NWO and its divisions were bypassed by ICES/KIS and the researchers, which compromised or potentially compromised availability of resources, in particularly those provided by researchers. Thirdly, it is this, more than the new field, that triggered them to an endeavor to regain influence on national developments in nanotechnology.

7.2 The Dutch research funding constellation

Outline of Dutch research funding and industry

In terms of gross domestic product, the Dutch economy is based on a diverse set of sectors, including manufacturing (with a large share of food products and beverages), trade and retail, transport, financial and business services, and government. From the late 1960s until 2005, relative sizes remained more or less the same with the exception of the financial and business services which grew from around 10% to 20% of the total, and the manufacturing sector which shrunk from around 25% to 15% (CBS, 2008, p. 48 - 51). The Netherlands houses a few multinational companies which relate to nanotechnology. These include firms in electronics and microelectronics such as Philips and ASML, the chemicals company DSM and TenCate textiles.

In 2004, the Dutch public research sector comprises 13 universities, including one university for agricultural research and education, and 3 technical universities. In addition, there are over 30 public research institutes of various sizes and shapes. Most are financed by the Ministry of Education, Culture and Science but other Ministries finance 'their' sectoral institutes as well. (McKibbin, 2004, p. 7)

Dutch Government is supported by a dense network of advisory bodies, RFOs and other intermediaries. Amongst these are the Advisory Council for Science and Technology Policy, 5 Advisory Councils on Research[208], the Koninklijke Nederlandse Academie der Wetenschappen (KNAW - Royal Netherlands Academy of Arts and Sciences), and the Innovation Platform which was established in 2003 and is chaired by the Prime Minister. (McKibbin, 2004, p. 6 - 12; Van der Meulen & Rip, 1998)

The Dutch science-technology divide

The Dutch RFO constellation in outline can be characterized as a science-technology divide. On the science side operates the *Nederlandse organisatie voor Wetenschappelijk Onderzoek* (NWO - Netherlands Organization for Scientific Research) with its semi-independent divisions. On the technology side of the divide operates an RFO called SenterNovem. SenterNovem is described briefly because its role in this chapter is limited. NWO and its history are described in detail in order to show how the Ministries' bypassing of NWO contrast to its mission and capacities which it built up to pursue that mission.

[208] The councils consist of representatives of research organizations, users of research, groups interested in the effects of research, and government agencies. (Van der Meulen & Rip, 1998, p. 760 - 761)

No technology RFO existed until 1994 when Senter was established as an agency of the Ministry of Economic Affairs. In Senter, two service departments of the Ministry were merged. Its main tasks were the administration and implementation of the Ministry's subsidy instruments, preparation of such instruments, signaling relevant developments for these instruments, and mediate between private companies and between companies and research organizations. (Berndsen, Klützow et al., 1998) In 2004, Senter merged with Novem, an agency for energy and environment research and policy. (SenterNovem, 2009)

SenterNovem takes assignments and receives budget from the Ministry of Economic Affairs. It can suggest programs to the Ministry but cannot launch them on its own initiative. The RFO has in house experts who review project applications and organizes internal expert committees to internally aggregate knowledge about promising fields of research and development, combine knowledge about networks.[209]

It operates a number of R&D funding instruments and programs, including the Point One program, which carries the subtitle 'nano electronics and embedded systems'.[210]

NWO, and the current NWO divisions which played, and still play, a role in the coming about of nanotechnology in the Netherlands, were established after World War II. The first was the foundation Fundamenteel Onderzoek der Materie (FOM - Foundation for Fundamental Research on Matter) which was established in 1946 as a research institute for basic research. In the following years the *Nederlandse Organisatie voor Zuiver-Wetenschappelijk Onderzoek* (ZWO - Netherlands Organization for the Advancement of Pure Research) was established, and during the decades to follow, a number of research institutes and foundations were erected and funded through ZWO, but operated independently of each other. FOM, ZWO and their institutes were financed by the Ministry of Education and Science. (Kersten, 1996)

During the 1960s, FOM researchers articulated their interest in research programs that were not only of high scientific quality, but that would also be oriented towards application. In 1976, FOM started a program *Technical Physics and Innovation*, which was supported by the Ministry of Economic Affairs. Proposals within that program were reviewed both on scientific quality and on utilization potential. The program attracted attention and it was part of the developments that lead to the creation of the *Stichting Technische Wetenschappen* (STW - currently known as Technology Foundation STW) in 1981 (Le Pair, 2001; Van den Beemt & Le Pair, 1991).

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[209] Interview with C. Langerak.
[210] Interview with C. Langerak.

Although STW at that time was directly funded by the Ministry of Economic Affairs, government did not want to remain directly responsible. STW was to be located under ZWO. (Le Pair, 2001) At present, STW is financed both by the Ministry of Economic Affairs, and through NWO, also by the Ministry of Education, Culture and Science.

STW adopted a review system based on bottom-up applications which comprised two reviews, one by five expert peers and one by a jury of 12 members who had widely varying backgrounds, not related to the proposals. Both reviews assessed scientific quality and utilization potential. STW's Board took the final decision. (Van den Beemt & Le Pair, 1991) Afterwards, as a result of pressure from NWO, STW bundles its applications in programs[211].

As of 1979, successive Ministers wanted an RFO that not only responded to scientific developments but also to societal developments. It took them almost 10 years of negotiations with ZWO, but as of 1988, ZWO was replaced by the Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO - Netherlands Organization for Scientific Research) (Kersten, 1996, p. 338, 364 - 403).

In order to fulfill the mission of its new societal orientation, NWO introduced a new instrument, the so called priority programs. NWO also aimed to make this instrument available to Ministries that wanted to implement particular targeted research programs (NWO, 1989, p. 12). In the course of time, the range of instruments expanded. NWO developed or became involved in a host of funding programs, amounting to more than 60 in 2008 (NWO, 2008b).

Another important difference between NWO and ZWO was NWO's organizational division in semi-independent *Gebiedsbesturen* (Division Boards) for scientific disciplines under NWO's Governing Board. Each Division Board not only stimulated research through project and program funding, but could also operate one or more research organizations. FOM, for example became a foundation under the Division Board for Exact sciences (NWO, 1989, p. 0)[212]. Finally, an important difference between ZWO and NWO was that the Minister of Education and Science was not represented in NWO's Governing Board.

Compared to the preceding period, representation in the Board and ad hoc contacts between ZWO and the Ministry were replaced by more regular and formalized contacts every four to five months. This created a distance between the two and increased strategic deliberations.[213]

In the course of the 1990s, the Ministry of Education and Science moved all its program funding instruments with the accompanying budgets to NWO. The Ministry also attempted to convince other ministers to run their research funding programs through NWO as well. This happened a few times, but did

211 Interview with D. Reinhoudt. Personal communication B. van der Meulen (June 11th, 2009) Recently, the Ministry of Economic Affairs wanted STW to develop top-down targeted programs with the Ministry's budget share.

212 Later, FOM became the single institute of a new Division for Physics.

213 Interview with P. Tindemans.

not last. Furthermore, the Ministry of Health agreed to merge its RFO for applied medical research with NWO's Division for Medical Sciences.[214]

The Ministry also transferred its budget for investments in equipment to NWO. As of January 1st 1994, NWO operated two funding programs, viz. NWO-middle for applications up to Fl. 2 M and NWO-big for applications above Fl. 2 M with a total of Fl 30 M. NWO-middle proposals ran through NWO's divisions, NWO-big proposals through an advisory committee and NWO's Governing Board[215]. (NWO, 1995, p. 12)

As of 2001, NWO housed the Nationaal Regieorgaan Genomics (National Orchestration Body Genomics - my translation), currently known as Netherlands Genomics Initiative. This organizational body was installed to manage a priority program financed by five ministries which together invested € 200 M in a five year program (NWO, 2002). Although it was located at NWO, it was not controlled by NWO. Later, two[216] other orchestration bodies[217] were added to NWO as well. Through them, NWO's expertise in managing funding programs is made to good use to implement priority programs funded and controlled by varying consortia of Ministries, industrial parties and NWO.

Thus, on the science side of the Dutch science-technology divide, NWO became the single science RFO with instruments to finance societal needs oriented research through funding programs. Its divisions however remained independent to a large extent. They could launch their own funding programs, could develop their own policies, and depending on the division maintained direct ties with ministries.

7.3 RFOs plan the lead

Nanotechnology became visible to researchers, RFOs and research policy makers through several foresight reports published by three foresight and advisory councils. NWO's divisions also started financing nanotechnology research through bottom up funding. As of 2000, divisions and NWO's Governing Board also prioritized nanotechnology in the course of strategy making processes. For this, they aggregated input from wide circles of

[214] Interview with P. Tindemans.

[215] In the course of the following years, the budget ranges remained the same. In 2007 NWO-middle financed up to € 900 000. (NWO, 2008a, p. 23)

[216] These are the Advanced Chemical Technologies for Sustainability (ACTS) and the Netherlands ICT Research and Innovation Authority.

[217] NWO's English webpages use the translation Temporary Task Force. Orchestration body is my translation.

researchers. It was a partly bottom-up process but not proposal based and also partly top-down.

Passive funding through business-as-usual

In the second half of the 1990s, four different organizations identified nanotechnology as a promising newly emerging field of research. The Overleg Comissie Verkenningen (OCV - Consultative Committee on Foresight), which was established in 1992, commissioned a foresight study in 1995 and included nanotechnology in its 1996 foresight report as one of over 30 research fields. (Garrelfs & Oosting, 1995a, 1995b, 1995c; OCV, 1996) A few years later the STT[218], a private foundation for foresight of technology and society, published a foresight study on nanotechnology (Ten Wolde, 1998) and organized a symposium about the theme. Also in 1998, the NRLO published an action program for nanotechnology and presented it to the Agricultural University and STW (Chehab & Enzing, 1998; NRLO, 1999).

NWO and its divisions also had noted the new field. In the course of the 1990s, FOM financed several projects carrying the nano-label in their title through its open project funding instrument. In 1994, NWO and Delft University of Technology invested Fl 8.6 M on equipment within the *Nanoschaal Experimenten en Technologie* (Nanoscale experiments and technology - my translation) program which ran at the Delft Institute of Microelectronics and Submicron Technology (DIMES) (FOM, 1995, p. 9; NWO, 1995, p. 46).

As of 1996, FOM introduced a program funding instrument. This was part of a new policy to implement a restructuring of NWO which in turn was the result of an evaluation of NWO in 1996 (FOM, 1997, p. 6 - 7). FOM was to change into an organization for programmatic funding, not only for FOM's own institutes and work groups but also for other researchers. It was a bottom up instrument, so that researchers could submit program proposals. FOM's Executive Board made final decisions after international peer review. (FOM, 1999, p. 7-8).

In 1998, the first 42 programs were identified, which included 3 programs carrying 'nano' in their respective titles:

- Nanotechnology and nanoelectronics, 1998 - 2005, Fl 4.9 M
- Single-molecule detection and nano-optics, 1999 - 2005, Fl 2.8 M
- Nanostructured opto-electronic materials, 1999 - 2003, Fl 12.3 M, prolonged to 2007

Also in 1998, STW relabeled a three year program from 'Stappen in het micrometer gebied' (Steps in the micrometer area - my translation) to 'Stappen in het micro en nanometer gebied' (Steps in the micrometer and nanometer area - my translation). (STW, 1998, p. 23; 1999, p. 22)

[218] STT uses no English name.

Prioritizing nanotechnology through business-as-usual

In 2000, NWO's Division Board *Chemische Wetenschappen* (CW - Division for the Chemical Sciences) selected four priority areas within chemistry for the years ahead: sustainable chemistry and technology, chemistry and life sciences, molecular nanosciences, and new research methods. Apparently, CW restricted itself to molecular nanosciences. This field showed fascinating results: guided by inter molecular interactions, individual molecules can organize themselves into bigger structures with nano size and special functional properties. This offered possibilities for molecular motors, electrical circuits and other applications. New research techniques were being developed which were of interest to both chemistry as well as physics, such as detection and manipulation of individual molecules, computer simulations of catalytic processes and folding of bio macro molecules. (NWO, 2001a, p. 29 - 30)

CW arrived at this choice through an elaborate process which involved portfolio analysis and extensive discussion with several actors. CW had developed a procedure to arrive at policy choices that involved an analysis of the program and project portfolios to see whether trends are visible. Here, open funding and the talent[219] program have a strong signaling function. They may show for example that young researchers chose different topics or questions or use different concepts such as 'nano' to indicate or identify their work. The portfolio analysis may also reveal changes in the group of applicants: for example applicants may show up who have been professors for a long time but have never before applied at CW. Further, it makes cooperation patterns between researchers and changes in these patterns visible. Although these analysis are enlightening, Board members often see changes somewhat earlier than the policy makers at CW.[220]

Besides the portfolio analysis, there were contacts between NWO's Board and the CW Board to exchange and coordinate wishes and plans in both directions. CW also invited representatives of its sixteen study groups for scientific input from the chemistry field in the developing of policy plans. These study groups consist of researchers in different topics within chemistry. They each organize an annual meeting to keep researchers from the Netherlands up to date and in contact with each other[221].

CW funded a program nanosciences (my translation) from 2002 (or earlier) until 2006 with a budget of about € 0.5 M. See Table 7 on p. 151 for more details about the budget.

[219] The talent program is an NWO wide program which is aimed at promoting especially talented researchers from junior to senior level. The grants are provided to the persons, rather then to their institutes and are considered prestigious.
[220] Interview with I. Ridder.
[221] Interview with I. Ridder.

After CW had prioritized nanotechnology, some struggles and debates with FOM, STW and the Division of Earth and Life Sciences followed about how to handle the field. The divisions debated questions such as how should the field be approached and how should industry be involved[222]. These discussions lead to an NWO wide priority for nanotechnology, which NWO published in May 2001 in its third multi annual plan.

The plan covered the period 2002 to 2005 and identified nine Themes which cut across the divisions and which were elected as strategic priority areas (NWO, 2001b). This initiative was meant to "ensure that Dutch research remains at the forefront internationally, NWO plans to invest heavily in renewing the research agenda." (NWO, s.a.-b). It identified the following themes: Cultural Heritage, Ethical and Social Aspects of Research and Innovation, Shifts in Governance, Cognition and Behavior, Fundamentals of Life Processes, System Earth, Digitalization and Information Technology, Nano-Sciences, and Emerging Technologies.

NWO used a bottom up strategy to fill in the Themes with funding programs. That is, NWO left it to its divisions to develop coordinated programs. By the end of 2001, the divisions had consulted with their researchers and developed twenty programs which gave content to eight Themes: Nano-Sciences was not covered.

NWO did not present ideas of how to organize the Themes, but announced that for each one a suitable way would be developed before the end of 2002 (NWO, 2001b, p. 8, 38). For the Nano-Sciences, NWO's Governing Board offered € 1,3 M if the Divisions would develop a plan (Zachariasse, 2003, p. 10)[223]. € 1,3 M can hardly be considered to reflect a priority, considering the size of NWO's total spending of more then € 400 M in 2002 (NWO, 2003, p. 119) [224]. A committee was set up, but it failed to produce a plan[225].

7.4 Researchers and government take the lead

In this section, the development of a Governmental research funding program in the early 2000s appears an opportunity to a consortium of research groups from three different universities. After two earlier unsuccessful attempts at

[222] Interview with I. Ridder.
[223] Interview with M. Zachariasse and H. Van Vuren.
[224] For 2002 and 2003 € 0.5 M was spent on the Nano-Sciences theme on a total of €38.7. In 2003, planned investments for 2004 to 2006 totaled € 118.7 M, including € 0.2 M for Nano-Sciences. The biggest Theme was System Earth with € 36 M planned investments for 2004 to 2006. (NWO, s.a.-a, p. 7)
[225] Interview with D. Blank.

programs of the Ministry of Education, Culture and Science, and the Ministry of Economic affairs, they develop the NanoNed proposal.

Developing a governmental funding program while bypassing NWO

One source of income of the Dutch state and the Dutch economy consists of sales of gas reserves that were found in in the North East of the Netherlands. The government invests returns of these gas fields in Dutch infrastructure to support economic developments. As of 1993, a part of that budget is being invested in support of the Dutch research infrastructure. During the first round in 1994, about Fl 250 M was spent on research without a formal review procedure. Within the organizing committee the few persons with a science background, such as P. Tindemans, were largely instrumental in putting together the final list of proposals from the different Ministries[226]. The second round which followed four years later, had a more formalized procedure, but a general critique on that process was that it was too much top down organized. Ministries were allowed to propose projects and were free to organize this as they saw fit. This resulted in a rather opaque situation and many parties involved had the impression that grants were largely dependent on good contacts between parties and ministries (Ernste, Deug et al., 2005, p. 17).[227].

The latest investments through this fund were arranged through the 'Besluit subsidies investeringen kennisinfrastructuur' (Decision subsidies on investments in knowledge infrastructure - my translation) better known as BSIK, which was published in December 2002. This third round introduced the 'Committee of Wise' which advised the Ministers. Government wanted to have a more transparent selection process in which applicants would know application criteria in advance and could receive feedback on why proposals were not granted (Hoogervorst, 2002). BSIK is also known as ICES/KIS 3, in which name ICES/KIS is the acronym of the inter ministerial committee for knowledge infrastructure investments.

The third round would distribute about € 800 M to consortia of research groups/institutes and companies over the period 2003 to 2010. The subsidies were provided on the basis that the consortia would match on fifty-fifty basis, which meant that this round would cover investments of about € 1600 M, or about € 200 M per year[228]. Not counting the matching budgets, BSIK spent as much per year as one fourth of NWO's expenditures in 2002 (NWO, 2003, p. 119).

[226] Interview with P. Tindemans.
[227] No further details available to me at present.
[228] Not all programs ran for four years. Some lasted five years or more.

A ministerial working group had started preparations by the end of 1999[229]. In April 2000, it commissioned the consultancy firm KPMG to develop a list of potential themes for funding. KPMG interviewed 120 actors in ministries, advisory councils, research organizations, consortia that received grants from the second investment round, and non-governmental organizations. These and sent in suggestions amounted to about 200 ideas which KPMG grouped into seven themes: systems innovation, computing and communication technologies, integrated system for multi functional and high quality use of space, knowledge transfer within small and medium sized enterprises, sustainability (in the economy, technology, ecology and culture), and breakthroughs in health, food, genetic and bio technologies. The working group followed this suggestion but felt that the themes needed better arguments to legitimize spending the budget on them. Therefore, it commissioned separate thematic reports from different experts in the second half of 2000. The working group also added nanotechnology to the list. (Ernste et al., 2005, p. 16, 25, 33)

Developing a nanotechnology proposal

Around 1997, D. Reinhoudt, professor at the University of Twente and scientific director of the MESA research institute[230], financial director C. Eijkel, and researchers from BioMade at the University of Groningen and DIMES at Delft University of Technology teamed up and wrote a project proposal called Nanolink for NWO's *Dieptestrategie* (Bonus incentive scheme) program[231]. The proposal was rejected. Reinhoudt assumes that the review committee's unfamiliarity with nanotechnology played a role, but one official point of critique was that the co-operation between the institutes was rather ad hoc. The consortium could not show a track record of cooperation[232].

A few years later, the group applied at the Ministry of Economic Affairs' Dreamstart program. Dreamstart was a support program for technology startup companies which was launched in August 2000 (Ministerie van Economische Zaken, 2000). The proposal was declined, but Reinhoudt kept discussing the need for a nanotechnology proposal with K. Vijlbrief of the Ministry of Economic Affairs. At some point Vijlbrief, Director Innovation Policy, who also was chair of the BSIK steering group, suggested that the researchers develop a proposal for a nanotechnology program. They did so by taking four projects from the Dreamstart proposal that were most industry oriented and titled it *NanoImpuls*. This proposal was granted € 22,7 M from the Ministry's

[229] The working group advised the ICES/KIS committee, which in turn advised the Government.
[230] Reinhoudt stepped back as director in 2007. MESA later was renamed into MESA+
[231] Interview with D. Reinhoudt
The bonus incentive scheme was aimed at promoting the best national post graduate schools. (NWO, 1999, p. 11 - 12)
[232] Interview with D. Reinhoudt

Kennisimpuls program (Knowledge Impulse - my translation) by the end of 2002.[233]

The Ministry of Economic Affairs had actively tried to develop a consortium for nanotechnology during the years that a list of themes for ICES KIS III was being developed (Ernste et al., 2005, p. 33). The Ministry had asked the NanoImpuls[234] team to develop the thematic report for the nanotechnology team. This report turned out as a proposal, called 'Masterplan Nanotechnologie'. It was finished by the beginning of 2001 and included plans for DIMES, MESA+ and BioMade. By then, the University of Eindhoven had complained about the proposal at the Ministry and rumors existed about other complaints from the Universities of Nijmegen and Wageningen. The Ministry saw problems arising and asked P. Tindemans and STW director L.J. Halvers to develop a solution[235].

Tindemans and Halvers made a tour along the universities to get them organized in one proposal. These included the universities of the 'Masterplan Nanotechnologie' and the other three universities. Based on his knowledge of the Dutch universities, Tindemans knew that other universities and institutes with serious physics and chemistry departments were not interested.[236]

Tindemans wrote an initial memo and organized talks and workshops to develop the outlines for a proposal. He suggested to organize the proposal around 'flagships' and agreed with the NanoImpuls trio that three facilities were enough for Holland. In addition, he acknowledged a need for equipment at the other three institutes. This and more was laid down in a proposal of July 11th, 2001. Later, the participating universities and groups developed it further into a final proposal called NanoNed[237].

By the end of 2003 after a review procedure which covered scientific, societal and economic quality, the Minister of Economic Affairs announced the government's decision to support thirty three proposals with a total of € 678 M. NanoNed received € 95 M, which made it by far the biggest proposal. The second biggest proposal received € 52 M, whereas the average budget was about € 20 M. (Hoogervorst, 2003) The NanoNed program started in January 2005 and will end in 2009[238].

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[233] Interview with D. Reinhoudt.
[234] Interview with P. Tindemans.
[235] Interview with P. Tindemans.
[236] Interview with P. Tindemans.
Tindemans saw this was confirmed by STW and by the fact that the other universities later did not complain
[237] Interview with P. Tindemans.
[238] Although the decision was made in 2003, the NanoNed program could not start directly because the subsidy had to be reported to the European Commission and evaluated against European Union regulations on R&D support. The European Commission approved of the subsidy in November 2004 (Monti, 2004).

The NanoNed program

The NanoNed program revolves around the following definition of nanotechnology which stresses individual addressability of the atom, molecular and supra-molecular structures:

> " Nanotechnology is understood to mean:
> being able to work at the scale of atoms, molecules and supramolecular, individually-addressable structures (from 1 nm to 100 nm), in order to produce larger complex-functional structures with a fundamentally new molecular organisation. Nanotechnology makes it possible to develop materials and systems, in which the components and structures exhibit revolutionary new, physical, chemical and biological characteristics, phenomena and processes that are associated with the nano-dimensions." (NanoNed, 2005a)

NanoNed describes the field as a multidisciplinary mix of three fields, viz.

> " • top-down technology of micro-electronics and microsystem technology,
> • bottom-up technology via chemistry and self-organisation (supramolecular chemistry) and physics and
> • biotechnology of natural functional molecules and the manipulation of these." (NanoNed, 2005a)

Part of the NanoNed budget is spent on eleven themes, called flagships:
- Advanced Nano Probing
- BioNano Systems
- Bottom-up Nano Electronics
- Chemistry and Physics of Individual Molecules
- Nano Electronic Materials
- Nano Fabrication
- Nano Fluidics
- Nano Instrumentation
- Nano Photonics
- Nano-Spintronics
- Quantum Computing

Each flagship has a director, called flagship captain, and is divided in up to four clusters of 6 to 14 projects[239]. Besides these programs there is a separate flagship on Technology Assessment and Ethical, Legal and Societal Aspects (TA / ELSA). All the projects were already defined in outline in the NanoNed application[240]. The programs have Users' committees consisting of the flagship

[239] Interview with L. Gielgens.
[240] Interview with D. Reinhoudt.

captain, potential users of the research and other knowledgeable persons on the applications of the research's results (NanoNed, 2005b).

The program has a "Valorization platform" for coaching and monitoring of the program's valorization activities, viz. knowledge transfer and "attention ... paid to societal output and the innovation proces[sic.]" (NanoNed, 2005c).

Finally, about € 80 M of the NanoNed budget[241] is being reserved for investments in laboratories and equipment via the NanoLab NL program within NanoNed. Four locations[242] in the Netherlands together constitute the NanoLab NL. NanoLab NL is managed by a steering committee with representatives from the four locations, Philips Research and the NanoNed secretariat. Like the research projects, investments in these locations are also made according to the granted NanoNed proposal. Because research develops in unforeseen ways, there is some flexibility to deviate from that plan after discussion with all participants (NanoNed, 2007).

NanoLab NL makes a distinction between basic equipment and expert equipment. Basic equipment can be found at all four locations, whereas each location has its own unique facilities and/or expertise (NanoNed, 2008b). The facilities are open to other researchers from the local institutes, researchers from NanoNed or MicroNed[243], and other users including companies. (NanoNed, 2008a).

All successful consortia of BSIK were free to organize their respective programs' management as they saw fit. SenterNovem would distribute the funds and monitor the programs, but apart from that they were free.

The NanoNed program decided to delegate the program's administration to STW, rather than to develop its own. This decision was based on Reinhoudt's positive experiences with STW when he was member of STW's Board, and STW had also hosted the preparatory meetings. The NanoNed consortium at present pays for five employes at STW, some of whom were recruited from within the consortium's partners. STW administers the combined budgets of NanoNed and NanoImpuls[244] as far as Government's investments go. Matching contributions are managed by the matching universities and companies of the consortium.[245] The close relation between STW and the NanoNed consortium may have played a role in STW and FOM's attempts to link up with the national agenda setting for nanotechnology.

[241] That is € 80 M of the combined government investments in NanoNed, NanoImpuls and the research organizations' matching funds.

[242] Zernike Insitute for Advanced Materials at Groningen University, MESA+ at the University of Twente, Kavli Institute of Nanoscience at Delft University of Technology (previously DIMES) and TNO Science & Industry in Delft

[243] MicroNed was one of the other granted proposals within the microsystems and nanotechnology theme of BSIK.

[244] The NanoNed and NanoImpuls programs were merged, so that they were both ruled by the conditions of the NanoNed program. Interview with D. Reinhoudt.

[245] Interview with L. Gielgens. Interview with D. Reinhoudt.

7.5 NWO's divisions respond to the new situation

At the latest when the BSIK funding decisions were published in November 2003 but probably earlier[246], NWO's divisions considered their position. NWO's new multi annual plan had prioritized nanotechnology, but no concrete program was developed and only a small budget set aside. Would it still make sense to develop something in parallel? Policy makers and Board members at CW wondered whether there would be enough room for an academic funding program next to BSIK. It was estimated that some interesting research questions would be left unaddressed. However, in view of the impact and the energy that already had been invested in the NanoNed application and in view of the size of the program compared to CW's means, CW did not see how it could add substantially to that[247]. Instead, CW decided to focus on one of the other BSIK programs[248].

By the end of 2002 or the beginning of 2003, a debate developed within FOM on how FOM should best position or reposition itself scientifically in view of recent developments[249] (Zachariasse, 2003, p. 6). Within FOM, nanotechnology was not clearly visible and FOM policy makers wanted to have an overview of its activities in the field. Since nanotechnology had become a buzzword, it was felt that it became time to participate so that FOM would not be overlooked[250].

Compared to CW, FOM had different reasons for taking it more seriously than it already had been doing since 1998: others were taking it seriously, so much so that large sums were made available, and FOM did not want to stay behind or be overlooked. Whereas CW's interest was triggered by developments in the research layer, FOM's interest was triggered by governments' and other divisions interest in the new field.

In February 2003, FOM published a report (Zachariasse, 2003) which contained a summary of national and international developments in research policy and an inventory of nano research within FOM. It used the following definition of nano sciences:

> "Nanoscience is research in physics, chemistry, or biology on the atomic or molecular scale (sizes in one or more dimensions are between 0.1 and 100

[246] In December 2002, the Ministry of Economic Affairs published the procedure and the maximum available budget for BSIK. (Hoogervorst, 2002a)

[247] Interview with I. Ridder.

[248] Interview with I. Ridder.

[249] "een nieuwe discussie binnen FOM over hoe de organisatie zich - gezien all nieuwe ontwikkelingen - met betrekking tot 'nano' het beste wetenschappelijk kan positioneren of herpositioneren." (Zachariasse, 2003, p. 6)

[250] Interview with M. Zachariasse and H. Van Vuren.

nm) in which the nano sizes determine the system's (macroscopic) properties." (my translation)[251]

The report (p. 10 - 11) suggested that nano research can be divided into six fields[252], viz.

- Nano-electronics
- Nano photonics / optics
- Nano materials
- Bio nano sciences
- (Molecular) nanotechnology
- Nano instruments

With this description it took inventory of such nano science research within FOM's research programs and activities. 18 Out of FOM's 63 programs were partly or completely within nanotechnology. In 2002, FOM had spend about € 6,5 M on nano projects, which was about 10 percent of FOM's spending in that year. The report also identified 44 work group leaders[253] who participated in NanoNed. (Zachariasse, 2003, p. 10, 15 - 20)

With the report, FOM had a base to claim responsibility for policy development[254] and it did so in its strategic plan of October 2004 for the period 2004 to 2010. To develop this plan, FOM organized a conference in March to discuss draft plans with researchers and other actors from within and outside FOM. These included Board members, directors of FOM's institutes, committee chairs[255], and a few distinguished researchers. From outside FOM, representatives from companies, TNO, sciences departments of Dutch universities, KNAW, NWO's Board and division boards, the Ministry of Education, Culture and Science, and other organizations participated as well. (FOM/GBN, 2004, p. 7)

The resulting strategic plan made two moves. The first was that FOM announced a shift towards a more clear support of economic innovation. Basic science and scientific quality remained the main aims, but in the selection of priority fields FOM's board wanted to prioritize those fields that promise future contributions to the economy. These fields had to have a *toepassingshorizon* : an application horizon. (FOM/GBN, 2004, p. 5)

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[251] My translation of "Nanowetenschappen is fysisch, chemisch, of biologisch onderzoek op atomaire of moleculaire schaal (afmetingen in één of meerder dimensies tussen de 0.1-100 nm) waarbij de nano-afmetingen bepalend zijn voor de (macroscopische) eigenschappen van het systeem." (Zachariasse, 2003, p. 5, 6)

[252] My translations of the fields "Nano-elektronica", "Nanofotonica/optica", "Nanomaterialen", "Bionanowetenschappen", "(Moleculaire) nanotechnologie", "nanoinstrumentatie"

[253] FOM organizes information exchange and discussions between researchers in so called work groups. In 2002 there were more than 200 work groups (FOM, 2003, p. 105 - 107).

[254] Interview with M. Zachariasse and H. Van Vuren.

[255] The source is not clear about which committees are meant. FOM has advisory committees for some of its subfields and policy advisory committees for its institutes. (FOM, 2005)

Secondly, the plan introduced 'Nano physics / technology' as a new priority field. This new field was filled by moving existing programs from other priority fields to the new field. Two other already existing subfields Condensed matter and 'Atomic, molecular and optical physics'[256] were merged into one. Moreover, FOM's Board protected the new field from previewed cutbacks[257]. (FOM/GBN, 2004, p. 5, 16 - 17)

The priority field Nano physics/technology was defined similar to Zachariasse (2003) as discussed above, except that the strategic plan defined physics as the central part of the priority field, which, if necessary, may overlap with or connect to biology and chemistry[258].

To further typify this subfield, the strategic plan lists the following subjects[259]

- nano-(molecular) electronics
- nano photonics / optics (photonic materials, quantum dots, plasmonics)
- nano materials
- instruments for observation and manipulation
- nano fabrication
- quantum computing
- spintronics
- nano tribology
- physics of ultra thin layers

The strategic plan mentioned two reasons for prioritizing Nano physics. One reason was that nanosciences and nanotechnology were national and international hot topics and that FOM was spending about ten percent of its budget. The second reason was that the NanoNed program, being an application oriented program, needed a counter part in basic research. FOM would like to search for 'cross fertilization' between the 'complementary approaches' of the NanoNed program and basic science. In addition, FOM saw an excellent opportunity for a multi or interdisciplinary approach in cooperation with the NWO divisions Earth and Life Sciences, Chemical Sciences and STW. It wanted to develop the NWO Theme Nanosciences and indicated that it intended to invest € 3 M per year. (FOM/GBN, 2004, p. 39 - 40)

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256 My translation of ‘Atomaire, moleculaire en optische fysica’

257 Because of a drop in income and because the Board wanted to invest in a few new plans, it saw itself forced to cut back on the total budget of the priority fields in the course of the years from € 22,7 M in 2004 to € 8,7 M in 2010. It was expected that FOM's total budget would drop from € 77,7 M in 2004 to € 67,4 M in 2010. (p. 27, 29)

258 "Onderzoek binnen het subgebied Nanofysica/technologie is gedefinieerd als fysisch onderzoek (eventueel op grensvlakken met biologie en chemie) op atomaire en moleculaire schaal (afmetingen in één of meer dimensies tussen de 0,1 en 100 nm) waarbij de nano-afmetingen bepalend zijn voor de (macroscopische) eigenschappen van het systeem." (FOM/GBN, 2004, p. 17)

259 My translations of "nano-(moleculaire) elektronica", "nanofotonica/optica (fotonische materialen, quantum dots, plasmonics)" "nanomaterialen", "instrumentatie voor observatie en manipulatie op nanoschaal", "nanofabricage", "quantum computing", "spintronica", "nanotribologie", "fysica van ultradunne lagen" (FOM/GBN, 2004, p. 17)

So, contrary to CW a few years earlier, FOM did think that it still could make a worthwhile addition to research support next to the NanoNed program. FOM, did have a bigger budget than CW, although € 3 M per year is still far less then the € 20 M to € 22 M per year that is available through the NanoImpuls and NanoNed projects[260]. Moreover, part of the € 3 M had already been reserved for the running programs that were moved to the nano physics / technology field.

The Blank committee

FOM went ahead with its plan to develop the NWO Theme Nanosciences and together with STW, it established the Blank committee, named after the committee's chair, D. Blank. Blank, professor Inorganic Materials Science at the University of Twente and as of 2007 Reinhoudt's successor as scientific director of MESA+, explained that he and the other committee members were chosen in part because they were in a relatively young phase of their career, compared to the initial committee that was set up to develop an agenda for the NWO Theme Nanosciences[261].

The committee was established in January 2005 and its aim was to devise a national research program for nanoscience. It observed that in spite of NWO's 2001 strategic plan no structural funding program was launched. The NanoNed program was launched, but as the committee pointed out, it was only as a five year program rather than a long term structural program. (Blank, 2006, p. 2)

The committee prepared for its task by consulting other researchers. It identified about fifty researchers, based on its members' own knowledge and based on suggestions made by their contacts. This way, the committee extended its horizon and could aggregate the views of a large number of people.

The committee published its report in January 2006. It contained no definition or general description of nanotechnology. This was the result of Blank's personal opinion about what would suit a national research program for nanotechnology. The NanoNed program stressed individually addressable objects within the range of 1 to 100 nano meter. As Blank sees it, the field is bigger than that and not only in terms of the nano meter range. Nano particles would fall outside NanoNed's definition because they are not individually addressable objects but to Blank, they clearly belong to nanotechnology. Another example of nanotechnology that falls outside NanoNed's definition concerns making nano sized structures on surfaces.[262]

To Blank, defining the borders of nanotechnology is an intuitive thing. He would include manipulation on the scale of 100 nm or smaller, collectivities of

[260] Here, I am counting the government investments, not the investments plus matching funds.
[261] Interview with D. Blank.
[262] Interview with D. Blank.

nano scale objects which as a collective exhibit certain characteristics or properties, and he would be less strict with the difference between micro and nanotechnology because nanotechnology always involves making connections to the bigger environment in which it is applied[263].

Instead of providing a definition, the committee's report simply proposed three themes for a national program on nanoscience and nanotechnology, viz. Nanomedicine, Beyond Moore, and Functional nanoparticles and nano-patterned surfaces. These themes were selected in view of the strengths of a large number of Dutch research groups in combination with the "expected social and economic impact" (Blank, 2006, p. 3) of these themes. For each theme, the report provided an overview of the theme's scientific content, listed Dutch research groups that addressed it, and gave recommendations for a national policy. In addition, the report discussed eight research topics.

In May 2006, NWO published its strategic plan for 2007 - 2010. This supported the Blank Committee's proposal without further ado. FOM, STW and CW announced that they intended to develop a national initiative together with two other NWO Divisions, viz. Earth and Life Sciences and Medical Sciences (NWO, 2006, p. 54, 61 and 63).

NNI

After NWO had published its new strategic plan in May 2006, two developments in the Dutch research and research funding merged into one. FOM, STW and other NWO divisions were proposing a national research agenda, and through the strategic plan they applied for funding of that agenda at the Ministry of Education, Culture and Science. This development teamed up with NanoNed into the *Nederlands Nano Initiatief* (NNI - Netherlands Nano Initiative).

On November 16th, 2006 the Dutch Government released a White Paper on nanotechnologies. *Kabinetsvisie Nanotechnologieën. Van Klein naar Groots (*'Government vision on nanotechnologies. From small to grand' - my translation). The White Paper discussed many aspects of nanotechnology, such as economic potential and societal applications, risks and regulatory issues, ethical and judicial questions, research agenda, coordination, and societal support and communication. It identified five research themes for a national research agenda. These were the three identified by the Blank committee, the theme Water purification and Energy supply which resulted from a Rathenau report, and the theme Food and health as proposed by the NanoNed consortium. (Staatssecretaris van Economische Zaken, Minister van Onderwijs Cultuur en Wetenschap et al., 2006 p. 22)

[263] Interview with D. Blank.

The Government did not promise to invest in nano research, but left that decision to the next Government. At the time of publication, the Netherlands had an outgoing Government while awaiting elections, later in November. However, the Government found FOM, STW and NanoNed's initiative to develop a National Nano Initiative[264] interesting and announced that it wanted to ask them to take education, infrastructure and risk research into account. (Staatssecretaris van Economische Zaken et al., 2006, p. 6, 21 - 26)

The NNI was a result of Reinhoudt's efforts to arrange follow-up funding for NanoNed. He visited a number of directors of NWO divisions. In particular FOM and STW were interested in further developing the field, but at least until January 2008, their Boards had made no financial commitments.[265]

NanoNed, FOM, and STW interpreted the government's positive comments on their efforts as an invitation to further develop a national research agenda. In March 2007, the three published a preparatory note which sketched the outlines of a draft program based on the five themes identified by the government, plus an additional theme Risks and toxicology of nanotechnology. The NNI consortium aimed for a program that requires investments of around € 100 M per year for a ten year period. (Zachariasse et al., 2007, p. 3 - 4)

The note was discussed throughout the remainder of the year in a number of workshops, one for each theme. Compared to the Blank committee, the NNI consortium broadened the range of actors that it tried to involve in the workshops, in order to make it a nationally coordinated program. More researchers were approached and representatives from companies. Fourteen persons were asked to identify at least twenty five persons in their field or theme to invite for the workshops. During the workshops, attendees were asked to identify persons who, based on their qualities, should be included in a subfield. This resulted in around 170 researchers mentioning 250 persons.

Part of the discussions was the question how initiatives to stimulate and coordinate nanotechnology research in the Netherlands should be coordinated. The suggestion was made to use the form of a *regie orgaan* (Temporary Task Force, or orchestration body[266]). The idea was dismissed because the existing orchestration bodies functioned in different ways which made it unclear what such a body eventually would mean for nanotechnology.[267]

In September 2008, NNI published its strategic research agenda, containing four 'generic themes', viz. Beyond Moore, Nano materials, bio-nanotechnology, and nanofabrication, and four application areas, viz. Nanomedicine, Food, Energy and Clean Water. The agenda referred to an internationally existing

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[264] Apparently, some confusion exists about the name: National Nano Initiative or Netherlands Nano Initiative.

[265] Interview with D. Reinhoudt. January 2008 was the date of the interview.
Interview with I. Ridder.

[266] NWO's English webpages use the translation Temporary Task Force. Orchestration body is my translation.

[267] Interview with I. Ridder.

description of nanotechnology which is to design, characterize, produce, manipulate and apply structures on the nanoscale in which one or more dimensions typically (but not necessarily) have a size below 100 nanometer. It made clear that the label of nanotechnology only applies if special properties of particles or layers are related to this size criterion. (Blank, 2007, p. 8)

NNI intended to develop into a consortium for excellent research in which private enterprises participate, research facilities are brought together and valorization of research is promoted (p. 5). It continued its request for € 100 M per year for a 10 year period and indicated that the Government should raise 50% of that amount, industry 20 %, universities and research institutes 15%, and NWO and EU also 15%.

ICES/KIS 4 could be a source for that money, but if the Government is willing, it could also make money available from its regular budget[268].

7.6 Conclusion: Bypass dynamics

The Dutch science RFO, NWO, initially treated nanotechnology as a business-as-usual, which resulted in a fractioned funding pattern across the divisions involved. In 2001, through business-as-usual prioritization processes, it did prioritize the field in its strategic plan. Compared to its other priorities made little budget available and failed to develop a research agenda, let alone a cross divisional funding program. Soon after, NWO was bypassed by researchers in search of budget for their nanotechnology research agendas and related needs for equipment and facilities, and by Dutch Ministries who were in search of priorities for their investments in the Dutch research infrastructure.

Because of the financial size of these Government investments, they threatened NWO's resource position, the more so because another round of investments was likely. Researchers could go elsewhere and could withdraw their resource support to NWO. Another problem was that NWO's authority as a priority setting organization was undermined. Apparently, the government did not want to make use of NWO's skills and capacities in this matter. Thus, NWO's resource position was under pressure.

For the field of nanotechnology, NWO's response was of a strategic type. It tried to regain influence by developing a national research agenda for nanotechnology next to the Government funded NanoNed program. It was successful to the extent that NWO's divisions became involved in a consortium

[268] Interview with D. Reinhoudt.
In September 2007, the Minister of Education, Culture and Science made € 271 M available for the continuation of the Netherlands Genomics Initiative.

together with NanoNed and that its agenda was adopted. The consortium attempts to acquire resources for follow-up funding from the government, but NWO nor its divisions are developing plans to release funding from their own budget for the joint agenda.

Because the Government investment program had a priority category for nanotechnology and was aimed at improvement of the Dutch knowledge infrastructure, the applications for the program could develop an approach which was not fractioned by disciplinary funding structures and could align capacity building and research plans with necessary investments in equipment and infrastructure. The program's shape was thus dependent on the research interests of the collaborating groups.

To the initial consortium of three research groups, their success may have had an unintended consequence. In the process of developing the NanoNed proposal, they had to take other groups on board and coordinate the interests of all those involved. when the resulting NanoNed consortium became involved into NNI, the range expanded even further and the agenda transformed into developing a national research policy for nanotechnology. Changes in agenda's and definitions of nanotechnology in the course of these dynamics involving researchers and RFOs are the theme of the next chapter.

7.7 Figures of the Dutch case

Table 7: Overview of incomes and budgets of Dutch RFOs and nanotechnology programs (x 1 000 000)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.	Fl.
NWO										
• Total benefits	416	458	495	528	714	726	622	535	575	594
FOM										
• Income[269]	105	115	113	114	112	119	125	128	127	130
STW[270]										
• Total income/benefits	51	54	56	59	69	45	61	60	94	108
• Steps in the micro and nanometer area								8		
Chemical Sciences										
• Total benefits	-	-	-	-	-	-	-	-	-	-
ICES/KIS 1					250					
ICES/KIS 2									see p. 152	

Continued on next page.

[269] Source: FOM annual reports
[270] Source: STW annual reports. Due to reporting inconsistencies, year columns from 1990 until 1996 mention 'income', year columns 1997 and later mention 'benefits'.

Table 7 continued

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
	Fl.	Fl.	€[271]	€	€	€	€	€	€	€
NWO										
• Total benefits[272]	707	837	418	439	453	490	505	567	-	-
• Theme nanosciences			1.3							
FOM										
• Total benefits[273]	139	158	71	92	89	75	90	88	83	-
STW										
• Total benefits[274]	84	110	70	63	59	67	58	67	67	-
Chemical Sciences										
• Total benefits[275]	-	-	19	18	19	19	18	19	-	-
• Nanosciences	-	-	0.32	0.18	0.09	0.08	0			
Nanoimpuls[276]				23						
ICES/KIS 2	211									
ICES/KIS 3[277]					800					
• NanoNed[278]						95				

[271] At the time of introduction, € 1 equalled Fl. 2.2.
[272] Source: Annual reports. As of 2000, the figures include those of FOM, but not STW
[273] Source: annual reports. The increase of about € 20 M in 2003 is mainly due to a change in the reporting scheme.
[274] Source: STW annual reports. In 2003 additional one time benefits of € 81 M were reported as a result in a change of payment system.
[275] Source: Chemical Sciences annual reports
[276] Income from Ministry of Economic Affairs. (Hoogervorst, 2002b)
[277] Source: Hoogervorst (2003)
[278] Income from ICES/KIS. Source: Hoogervorst (2003)

8 Norway: ongoing dynamics shaping nanotechnology

8.1 Introduction

Around 2000, the University of Oslo decided to prioritize the field of materials research, which had recently changed or was in the process of changing from structural materials research into functional materials research. It organized a national consortium called FUNMAT and developed a research agenda which also addressed nanotechnology. After an unsuccessful attempt to secure funding at Norges Forskningsråd (NFR - Research Council of Norway), FUNMAT turned to the Ministry of Science and Education and convinced it of the need for funding. This was the start of a multi-step development of the NANOMAT program and its successor, NANOMAT phase 2, at NFR. These steps involved a shaping and reshaping of the program for materials research and nanotechnology.

One part of the shaping of the first NANOMAT program was the merging of the Ministry's labeled budget for materials research and a nanotechnology program which two NFR divisions had developed. One result of this was that nanotechnology was defined in service of materials research.

When the program was developed, NFR was in a state of reorganization, which also influenced the shape of the program. In 2001, NFR's functioning was evaluated and the evaluation resulted in, among other things, the introduction of a functional organizational structure, including a division for Strategic Priorities which operated a new instrument, the Large Scale Program (LSP) instrument, to address all types of research from basic research to innovation. In the course of 2002/2003 six LSPs were launched, one of which was NANOMAT. As a result, NANOMAT was a program that addressed basic and applied research.

After a few years, in the course of regular policy making processes, the Ministry of Science and Education presented its new multi-annual White Paper. It listed materials research and nanotechnology as one of seven priority areas. In response, NFR launched a working party to develop a National Strategy for Nanoscience and Nanotechnology. In view of nanotechnology's interdisciplinary character and its wide range of applications, the working party's proposal completely re-organized the position of nanotechnology in relation to both the White Paper's priority categories as well as NFR's LSPs and other instruments. Neither the Ministry, nor NFR followed this proposal.

NFR did reshape NANOMAT's follow-up program in line with the working party's subdivision of nanotechnology and its suggestions for funding of equipment and facilities which in turn were a further development of such instruments in the first NANOMAT program. Other changes introduced with the phase 2 was a 50-50 division of budget over projects for basic and applied research respectively and a decrease of attention to materials research. Phase 2 replaced nanotechnology's service role to materials research by a more common definition of the field.

This short overview outlines this chapter and gives an indication of the shaping and reshaping of ideas about nanotechnology and their uptake in program funding. The shaping of the program to a large extent was influenced by major and minor changes in NFR's resource dependence situation, including expectations of researchers and the Ministry of NFR's performance as an RFO with a strategic role.

Such a processes of continuous change is not only visible at NFR. It occurs in research and government as well. Above the change in direction of material research is mentioned. The chapter briefly discusses plans and framings of nanotechnology at other universities, which collectively put pressure on the Ministry and NFR to address the field. Finally, the chapter illustrates how in the course of time, a laboratory which originally was developed and financed for microtechnology research became positioned as a laboratory for nanotechnology research.

8.2 The Norwegian research funding constellation

During the past decade and a half, two major reorganizations transformed the Norwegian research funding organizations into the Norges Forskningsråd (NFR) as it is known today. The first comprised a merger in the early 1990s of the then existing six RFOs which were funded through multiple ministries into one council under primary responsibility of the Kirke-, Utdannings- og Forskningsdepartmentet (KUF - Ministry of Education, Research and Church Affairs). The second reorganization took place about a decade later when NFR's internal structure was changed from disciplinary into functional. NFR operates in a landscape of research and industry users, which is first described briefly.

Outline of Norwegian research funding and industry

In 1969, oil resources were discovered on the Norwegian continental shelf. Since then, the oil industry boosted the country's economy, in particular after 1975. In 2005, close to 30% of Norway's GDP and close to 50% of its export were on oil's account. The remaining 60% of GDP and 50% of export are carried by a diverse palette of wholesale, retail, hotels, transport and communication, health care, public services, business services, construction, utilities and agriculture, forestry and fishing. (Statistics Norway, 2008a, 2008b, 2008c) In relation to the off-shore industry, Norway developed a heavy-constructions industry for oil drilling platforms, pipelines and ships. Norway houses the world's third largest aluminum manufacturer. This in turn gave an impulse to structural materials research. Also Norway's industries for renewable energy such as hydrogen and solar energy, provide an industrial interest in materials research[279].

Until recently, Norway had universities in Tromsø, Bergen and Oslo, and one technical university, Norges Teksnisk-Naturvitenskapelige Universitet (NTNU), in Trondheim. In recent years three university colleges across the countries transformed into universities[280]. The universities are financed by the Ministry of Education and Research[281]. In addition, Norway houses a number of public research institutes, among which the Institutt For Energiteknik, which are funded by the Ministry of Education and Research or respective sectoral ministries (Arnold, 2001, p. 11-13). An actor that plays a side role in NFR's dealings with nanotechnology is SINTEF, an independent research organization for industry oriented research which was established in 1950. At present, it has seven divisions for health research, information and communication technologies, building and infrastructure, marine research, materials research and chemistry, petroleum and energy, and technology and society. (SINTEF, 2007)

A single RFO constellation

The first Norwegian RFOs were established shortly after the second world war. In 1946 the Norwegian Research Council for Scientific and Industrial Research (NTNF) was founded and placed under responsibility of the Ministry of Trade and Industry which also was its main budget provider[282]. (Skoie, 2000 p. 85)

[279] Interview with D. Høvik. Interview with H. Hvatum, L. Haaland and C. Gjersem.
[280] Interview with H. Hvatum, L. Haaland and C. Gjersem.
They are the University of Stavanger, the Norwegian University of Life Sciences, and the University of Agder.
[281] KUF changed its name on January 1st, 2002 into Utdannings- og forskningsdepartementet (Ministry of Education and Research), and again at January 1st, 2006 into Kunnskapsdepartementet. At the latter occasion, it kept the previous English name.
[282] See Schwarz, Irvine et al. (1982) for an assessment of NTNF.

Three years later, two other councils were founded. The Ministry of Agriculture launched the Norwegian Research Council for Agriculture (NLVF)[283] and the Norwegian Research Council for Science and the Humanities (NAVF) was founded under the Ministry of Church and Education (as it was named at that time) as a council for basic research. NAVF had four sub councils, viz. the medical research Council (RMF), the social science research council (RSF), the research council for the humanities (RHF), and the natural sciences research council (RNF). (Arnold et al., 2001, p. 34; Skoie, 2000 p. 85)

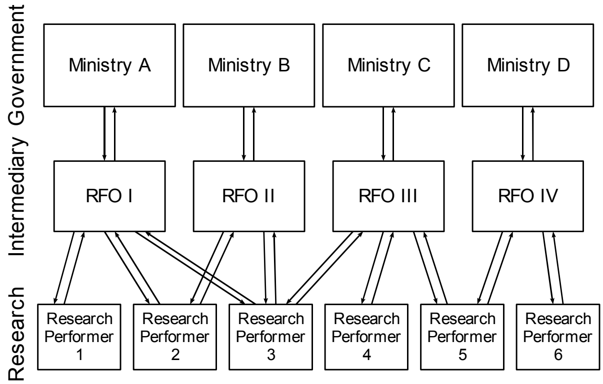

Diagram 6: Multi RFO constellation

The next addition to the group of councils came in 1972, when the research council for fisheries research was established at the Ministry of Fisheries[284]. A new sub council for 'social planning' (RFSP) was created within NAVF in 1978. In 1987, it became the separate Norwegian Research Council for Applied Social Science (NORAS). In the same year, a committee for environmental research was set up under NAVF independent of the other sub councils. The Ministry of the Environment channeled money for environment research through this committee. (Skoie, 1997, p. 65 - 66; 2000, p. 85) Thus, in the course of these decades, a Multi RFO constellation as schematized in Diagram 6 came into existence.

Several, more and less successful, attempts were made to coordinate the efforts of the RFOs. During the second half of the 1980s, the government channeled research funds through initially four 'growth areas'[285]. These areas crossed the boundaries of the research councils, which resulted in a complicated matrix structure of councils and their respective partial participations in these target areas. The Government's 1988 research White Paper strived for a simpler organizational structure. It set up an advisory committee, named after its chair K. Grøholt. Among other things, it proposed a merger of all councils into one and, in order to reduce the problem of coordination, proposed an organizational

[283] According to Arnold et al. (2001, p. 34) this council was founded in 1946.
[284] Acronym and responsible Ministry are unknown to me.
[285] Later, they became nine *hovedinnsatområder* ('main target areas'). See Mathisen (1996) for an account of the role of researchers in the development of these growth areas and the effects of such programs on research practices.

structure with three divisions. The commission also saw a need for integrating basic and applied research. After discussions in the Cabinet Research Committee, an Inter-ministerial Research committee, and with the research councils, a Government proposal was accepted in the summer of 1992. The resulting Norges Forskningsråd (NFR - Research Council of Norway) had six divisions and in addition to research funding also received the task of advising government[286]. Parliament's Standing Committee on Education, Research and Church Affairs wanted all resources made available to the new research council channeled through KUF[287]. (Arnold et al., 2001, p. 35 - 39; Skoie, 2000, p. 81, 85 - 89).

The Norges Forskningsråd officially started in January 1993 with the divisions Culture and Society (KS), Science and Technology (NT), Industry and Energy (IE), Bioproduction and processing (BF), Environment and Development (MU) and Medicine and Health (MH). NTNF was divided over NT and IE and former NAVF's Natural Sciences Research Council merged into NT with sections of NTNF. (Arnold et al., 2001, p. 39; Thuriaux & Arnold, 2001, Section C, p. 112).

NFR did not have a smooth start and suffered budget cuts in the following years. One particular problem was that Ministries did not channel all their research funds through NFR. They kept parts of their research budgets under their own control and labeled parts of the budgets that they did channel through NFR. Ministries that used to be responsible and main budget provider to research councils before the merger continued relations with 'their' respective divisions by being a dominant budget provider. In 2000, almost all divisions had one or two main budget providing ministries. Only the Environment and Development division had a somewhat different constellation of budget providers. (Van der Meulen, 2003, p. 326 - 321) NFR's resource dependence constellation is schematized in Diagram 7 on p. 158.

Each of the divisions also developed its own policies independent of other divisions and of NFR's board. NFR developed a set of funding instruments. It included: open project funding for peer reviewed basic research project applications, basic research programs for selected research fields, action oriented programs aimed at public sector priorities, user controlled programs aimed at industry in which industry also contributes financially to collaborative projects, core institute funding which is determined and provided by ministries, strategic institute programs (SIP) aimed at developing user relevant capacities at institutes, strategic institute programs (SUP) for targeted capacity building at university groups, and finally equipment funding. Divisions used different subsets of these instruments and they also distributed budgets differently over

[286] Previously, this task was in the hands of the Forskningspolitisk rad, which was abolished at the same occasion.
[287] At some point in between 1985 and 2000, the Ministry of Cultural and Scientific affairs was renamed into Ministry of Church Affairs, Education and Science.

these instruments. (Van der Meulen, 2003, p. 328)

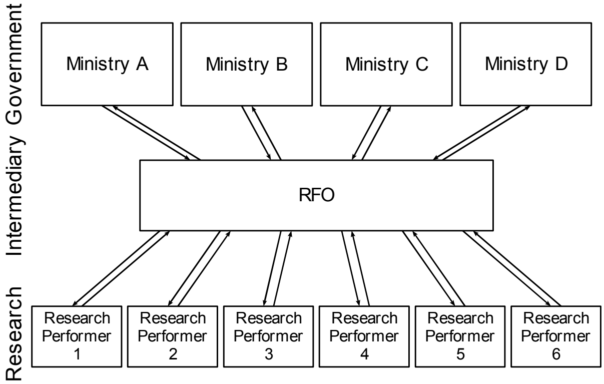

Diagram 7: Single RFO constellation

In 2000, KUF commissioned a broad evaluation of NFR[288], which eventually resulted, among other things, in an internal reorganization of NFR. The primary division differed fundamentally in that it was not based on a disciplinary or theme wise compartmentalization of research, but on NFR's main tasks of science promotion, policy advice and stimulation of innovation. As of December 2002, NFR's main divisions became the Division for Science, the Division for Strategic Priorities and the Division of Innovation. The previously existing disciplinary divisions had become departments within the Division for Science, be it that their number had reduced from six to five. The new Division had departments for Social Sciences, Humanities, Physical Sciences and Technology, Biology and Biomedicine, and Clinical Medicine and Public Health. The Division for Strategic Priorities consisted of the departments Future Technologies, Society and Public Policy, Marine Resources and the Environment, Energy and the Environment, and Global issues. The Division of Innovation included Strategy and Marketing, Innovation Programs, Industry-oriented R&D and Innovation Incentives, Competence-building, and the Department Bioproduction, International Cooperation and Commercialization. (NFR, s.a.)

The evaluation recommended that an instrument be introduced which covers all aspects from basic research to innovation. NFR followed up on that and this resulted, among other things, in the instrument of Large Scale Programs[289]. It took some struggling to acquire additional money from the Ministry though and eventually NFR did not get as much as it wanted[290].

In spite of budget cuts in the second half of the 1990s, NFR had gained a strong policy position around 2000, largely due to developments in the universities' budgetary position. Because of changes in the number of academic students in

[288] See Arnold (2001) and the accompanying background reports.
[289] Interview with D. Høvik. Interview with H. Hvatum, L. Haaland and C. Gjersem.
[290] Interview with H. Hvatum, L. Haaland and C. Gjersem.

the 1980s and 1990s, universities in the second half of the 1990s saw their income drop and had to cut back costs. This resulted in a situation in which universities spent most of their budget on personnel costs and hardly had any money available for additional research costs. University researchers therefor had become dependent on NFR[291]. (Bleiklie, Høstaker et al., 2000)

In addition, distribution of money to universities and within universities to departments were locked by historical practice and student numbers. This meant that universities were unable to change course in research, except through targeted growth. This also required external funding. (Arnold & Thuriaux, 2001, p. 28)

8.3 The NANOMAT program

NANOMAT's launch was a result of a merging of three developments. One comes from the field of materials research, which changed the orientation of its research agenda toward functional materials around 2000. Upon that, researchers from the University of Oslo, with the support of its rector, developed a nation wide consortium for functional materials research, called FUNMAT, which eventually secured funding at KUF. KUF labeled a part of NFR's budget to materials research.

The second development was the 2003 reorganization at NFR which influenced the choice of funding instrument, viz. a Large Scale Program. Thirdly, the reorganization coincided with plans to develop a nanotechnology funding program. NFR merged this program with the labeled budget.

From this short summary it already becomes clear that each of the three had its influence on the shape of nanotechnology. The program was a Large Scale Program, which determined its range of funding instruments and it became a materials research oriented program for nanotechnology.

Materials research, its quest for funding and a nanotechnology program at NFR

Around 2000, the Norwegian materials research changed its course from structural material research, which is oriented to materials for construction

[291] In terms of effectiveness, it remains an open question, because some scientists can make use of other sources, such as a few private funds and EU or Nordic funding. Moreover, Norwegian scientists find other ways, to propagate their own respective research agenda's. (Van der Most & Van der Meulen, 2001)

purposes, to functional material research, which is oriented towards far broader applications of functional properties of materials[292]. In the same period, NFR also funded a Strategic University Program called 'Films, Interfaces and Nanomaterials'. One of the program's aims was to establish a laboratory for the preparation of thin films at the University of Oslo (UoO). H. Fjellvåg was the main applicant and program responsible. (Nasjonal forskningsinformasjon, 2008).

Fjellvåg had been trying to find follow up funding for a program in physics and chemistry of condensed matter towards the end of the 1990s. His proposal to NFR was discussed but rejected, which to Fjellvåg meant that too little funding was available for basic materials research in Norway. During spring and early summer months of 2000, Fjellvåg became involved in talks between researchers of his university, the Ministry of Trade and Industry, and KUF. The Ministries were positive about his ideas for basic materials research and in May, Fjellvåg discussed matters with the Rector of his university. As of then the Rector and Fjellvåg Materials Research Group, organized a series of high level meetings with NTNU, SINTEF and IFE to develop a materials research program. During the autumn of 2000, a group of researchers wrote the FUNMAT document. In parallel, the UoO in another consortium also developed a plan for research in functional genomics with the acronym SAMGEN.[293]

FUNMAT was aimed at functional materials, but its agenda also addressed nanotechnology. The English summary of the program brochure explained that "Important areas of growth for modern industry, such as micro- and nanotechnology, are intimately related to research on new functional materials and advanced manufacturing methods" (FUNMAT, 2001). FUNMAT had six areas of research, one of which was 'Materials for nanotechnology'[294]. To finance the plan, an annual budget of NOK 150 M for a period of 10 years was needed. (FUNMAT, 2001)

The FUNMAT consortium approached NFR with its plans, but NFR, which had responded positively to the SAMGEN plan and developed the FUGE program on biotechnology functional genomics, did not finance the materials research initiative. At a later time, NFR argued that it could not launch a second big program next to FUGE.[295]

On February 23rd 2001, the Rectors of the UoO and NTNU officially handed the FUNMAT plans to deputy Ministers (statsekretærane) of KUF and of the Ministry of Trade and Industry. The plans proposed an annual investment of NOK 150 M in materials research. (Anonymous, 2001; Toft, 2001).

Fjellvåg developed contacts with KUF and argued for funding of materials research. In the course of 2001/2002 the Ministry also dealt with the EU's 6th

[292] Interview with H. Fjellvåg. Interview with J. Taftø.
[293] Interview with H. Fjellvåg.
[294] The others were Materials for energy technology, Materials for environmental technology, Materials for microsystems, Functional oxides and Biomaterials.
[295] Interview with H. Fjellvåg.

Framework Program. This focused heavily on materials research and nanotechnology and this convinced the Ministry that basic materials research and nanotechnology were important for Norway.[296] In the course of 2002, the Ministry labeled NOK 30 M of NFR's budget for functional materials research (Utdannings- og Forskingsdepartementet, 2002, p. 12, 132, 205).

The Ministry did not fund the FUNMAT consortium directly, because as a rule, it funds through NFR. The Ministry was interested in materials research and felt that it was worth strengthening, so it was willing to support the field, but not FUNMAT exclusively. At the Ministry it was felt that it could not decide whether FUNMAT or any other group is the best in the field, so competition was needed and organized through NFR.[297]

The NANOMAT program

During the same period, NFR's NT and IE divisions developed a funding program for nanotechnology. In February 2002, NFR decided to invest NOK 120 M in the program[298]. It started the same year and was planned to last until 2006. During this period, the NANOMAT program spent a total budget of around NOK 337 M (NFR, 2007c, p. 7). See Table 8 on p. 171 for a comparison with NFRs revenues and two other selected LSPs.

In 2002, a program officer, D. Høvik, was employed. He put together a preparation group chaired by A. Bjørseth, a former research director of Norsk Hydro, and further consisting of T. Ebbesen from the Louis Pasteur University in Straßbourgh and a number of Norwegian researchers. Høvik identified the group members based on his knowledge of nanotechnology and his personal network[299].

When in the course of 2002, the Ministry allocated NOK 30 M for materials research, this was added to the nanotechnology program. As of January 2003, NFR was reorganized from a disciplinary division into a functional division (see Section 8.2). In the course of 2003, the nanotechnology program moved from the NT and IE divisions to the Department for Future Technologies of the new division for Strategic Priorities (NFR, 2003a, 2003b)

A detailed description of the program shows that for a program for nanotechnology, it was heavily oriented towards materials research.

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[296] Interview with H. Fjellvåg.
[297] Interview with H. Hvatum, L. Haaland and C. Gjersem.
[298] Interview with H. Fjellvåg.
[299] Interview with D. Høvik.
Høvik received his PhD at SINTEF in 1978. From then until 2001, he worked at Norsk Hydro and the Jotun group. He, among other functions, had been Board member of SINTEF Chemistry, member and leader of the research and development group in trade associations of the Norwegian process industry, and Board member for a NFR program for process and materials technology.

The NANOMAT program brochure opened with the statement that nanotechnology and materials technology are "strategically important fields of research with a substantial commercial potential" (NFR, 2003b, p. 2). The program's general objectives were aimed at long term stimulation of Norwegian basic research in nanotechnology and materials technology. The aim was to reach a high international standard in selected fields. This should also make Norway an interesting partner in Europe[300] and elsewhere in the world (NFR, 2003a, p. 2).

The program brochure introduces nanotechnology as follows:

> " Nanotechnology includes nanoscience, and may be defined as:
>
> new techniques for synthesis and processing, including manipulation and assembly using nature's own building blocks (atoms, molecules or macromolecules), for the intelligent design of functional materials, components and systems with attractive qualities and functions, and where dimensions and tolerances from 0.1 to 100 nanometres (nm) play a decisive role." (NFR, 2003a, p. 2)

The structure of this definition revolves around the role of the synthesizing and processing techniques that are part of nanotechnology. These techniques serve 'intelligent design of functional materials, components and systems'. This differs from other definitions and descriptions in that they position functional materials and components and systems as part of nanotechnology's interdisciplinary character. By making nanotechnology serve materials research, the definition is in line with NANOMAT's combined support of nanotechnology and materials technology with stress on the latter.

Regarding individual aspects of the nanotechnology definition, the following can be remarked. The range of the nanoscale starts at 0.1 nm, rather than at 1 nm which is more common. The reason for this is that a group on mesoscopic computations and research wanted to participate in the program. This group worked at the 0.1 nm range, so in order to accommodate for this group, the scale range was defined to start at one tenth of a nanometer.[301]

The definition does not delve into nanotechnology's interdisciplinary character, as most descriptions do. The brochure adhered this characteristic to materials technology directly after the above quoted definition. "Materials technology is interdisciplinary, embracing physics, chemistry, biology, molecular biology, medicine, electronics and ICT." (NFR, 2003a, p. 2)

[300] Although Norway is not a full member of the European Union, it does participate in the EU's research union, in particular the Framework Programs.
[301] Interview with D. Høvik.

Elsewhere in the brochure, nanotechnology's interdisciplinary character is acknowledged implicitly or as self-explaining. For example, it is mentioned that the program is highly interdisciplinary (p. 4), and a list of "thematic priorities", also with a stress on materials research, is provided, consisting of:

" Nanotechnology and functional materials in:
    o Energy and the environment
    o Electronics, optics and communications
Nanomaterials
Other functional materials
Bionanotechnology
Design, theory and modelling
Infrastructure and nanotools
Ethics, the environment and society." (p. 6)

By the end of the program, about two thirds of the budget was spent on Nanotechnology and functional materials, Nanomaterials and Other functional materials. These figures indicate a general stress on materials/functional materials research which was agreed between the Ministry of Education and Research and NFR[302].

About NOK 139 M of NANOMAT's budget went to FUNMAT and NOK 18 M on COMPLEX. It comes as no surprise that FUNMAT could acquire such a big share. After all, part of the budget was allocated to functional materials research and FUNMAT was a strong group[303]. The criterion of nationally organized consortia in principle opened the program up for other applicants, but it meant that already existing consortia had a head start on those researchers who were not part of a consortium and had to build one from scratch. After discussions in the program board and after researchers who were not part of the two consortia commented on the criterion of nationally coordinated groups NANOMAT stopped using the criterion as a key for success in its calls for proposals[304].

302 Interview with D. Høvik.
303 Interview with D. Høvik.
304 Interview with D. Høvik.

8.4 A 'New nano program' and a new council

Whereas FUNMAT's successful lobbying of KUF can be considered a sudden change in NFR's resource position with a curious background, the prioritization of materials research was taken up in regular multi-annual priority setting procedures.

In 2003, when NFR's new functional organizational structure became operational, the latest Government long term research policy was the one of 1999, *Research at the beginning of a new era.* It prioritized marine research, information and communication technology, medical and health-care research, and research on the intersection of energy and environment (Ministry of Education Research and Church Affairs, 1999, p. 3). NFR used these thematic priorities as guideline for the selection of themes for its LSPs. However, the lists are not exactly the same and NFR added themes with FUGE, PETROMAKS and NANOMAT programs. After KUF's one-time labeling of budget for materials research, NFR included materials research in its 2004 strategic plan.

Government's next long term research policy White Paper, *Commitment to Research,* in turn shows many parallels with NFR's list of LSPs. The White Paper was published in March 2005 and contained four 'thematic priorities': Energy and environment, Oceans, Food and Health; and three prioritized 'technology areas': Information and communication technology, new materials and nanotechnology, and biotechnology.

The Ministry of Education and Research in which NFR roughly follows priorities after they have been articulated in White Papers, proposes priorities to government which in turn roughly follows NFR's proposal. Both retain some room for maneuver, by not following the other exactly. Meanwhile, the universities joined in by developing their own priorities for nanotechnology, also not unrelated to the other actors.

After the Ministry had prioritized nanotechnology in its White Paper, NFR set out to develop a new national agenda. It launched a working party which proposed a new way to approach nanotechnology, based on its interdisciplinary character and wide range of applications. NFR did not follow the working party, but developed the NANOMAT phase 2 program, which moved away from its predecessor's focus on materials research and also shifted stress away from basic research, thus reshaping nanotechnology as financed through the program.

NFR's 2004 strategy plan and the Government's 2005 White Paper

NFR's 2004's strategy plan was explicitly related to the Government's 2005 White Paper through NFR's policy advisory task (NFR, 2004a, p. 3). The plan was compact and most pages addressed a number of general goals: improving quality of research, promoting research that strengthens Norway's innovative and competitive capacities, expanding the dialogue between society and research, promoting internationalization of Norwegian research, expanding promotion of research talent, and finally improving NFR's functioning as an organization.

The strategy also prioritized a number of research areas. It explicitly followed government's latest research priorities, which meant basic research in all disciplines and research in the areas of marine research, medicine and public health, information and communication technologies, and the interface between environment and energy. Without further ado and without further describing them, NFR added the priority areas petroleum, materials and biotechnology (NFR, 2004a, p. 9), which made the total list of priority areas more or less covering NFR's Science Division and the LSPs of the Strategic Priorities Division, be it that in case of the NANOMAT program, only the materials research part of the program is reflected in NFR's priorities.

About half a year later, in March 2005, the Ministry of Education and Research published a new White Paper *Vilje til forskning* - Commitment to research. The Minister prioritized four thematic areas, viz. energy and environment, oceans, food and health, and three technology areas, viz. ICT, 'new materials and nanotechnology, and biotechnology. (Ministry of Education and Research, 2005, p. 8) Compared to NFR's strategy plan, the Ministry added a categorization to the priorities by distinguishing 'thematic areas' from 'technology areas'.

New materials and nanotechnology were approached from the change in orientation in materials research from structural materials such as steel, plastics and composites, to functional materials "whose use is connected to special chemical and physical properties" (p. 30) which "In recent decades ... have been decisive for technological breakthroughs" (p. 30).

> " Even greater expectations are linked to nanomaterials, i.e. materials that can be constructed at atom and molecule level. These will be able to supply new material combinations with completely new functions and areas of application." (p. 30)

Thus, the Ministry's view on nanotechnology was strongly oriented on materials research. The White Paper argued that if Norway was to participate in international developments, national investments in new materials and nanotechnology were needed. It mentioned that the ongoing investment resulting from FUNMAT will be continued in part through the NANOMAT program. (Ministry of Education and Research, 2005, p. 30)

NFR's response to the White Paper's nanotechnology priority

Right after publication of the government White Paper on research, NFR launched a working party to develop a national strategy for nanotechnology. B. Kasemo from Chalmers University of Technology in Göteborg, Sweden, chaired the working party. Other members came from the Universities of Oslo, Trondheim and Bergen, SINTEF ICT, and Elkem. The working party was assisted by a 'reference group' consisting of individuals from Norwegian, and one Danish, universities, research institutes, and companies. Also, representatives from the National Pollution Control Authority and the Technology Council were included and one observer from the Ministry of Trade and Industry were added to the reference group, which totaled twelve. The Director of the Future Technologies department attended the working party meetings as observer. NFR provided a secretariat of three people including NANOMAT's program coordinator, and arranged contacts with the Divisions for Science and Innovation. The working party submitted its report to NFR in August 2006. (NFR, 2007b; 2007c, p. 2)[305]

NFR asked the working party advice on, among other things:

- In view of Norway's needs and capacities, in which disciplines and communities should Norway become an internationally leading country?
- Which new areas could be identified and how should they be prioritized?
- Which measures should be taken to develop national coordination and division of labor, and in particular with respect to laboratories and equipment?

After providing background information on nanoscience and nanotechnology, describing developments in other countries[306], legitimizing Norwegian investments in nanoscience and nanotechnology, describing developments in Norwegian research and industry, and discussing societal issues, the working party's report answered the questions. It did so by proposing a dedicated approach to nanotechnology, or N&N, nanoscience and nanotechnology as it consistently referred to the field.

Because nanoscience and nanotechnology are so highly interdisciplinary and include so many technologies and applications it would be difficult to find their borders and this, the working party argued, is why N&N should not be

[305] The English version of the report, which is used here, was published in September 2007.
[306] These were Norway's neighbors, the United States, the European Union, and Japan.

approached through one separate program (NFR, 2007b, p. 36).

Instead, the working party proposed to stimulate nanoscience and nanotechnology broadly in two ways. One was to use the existing instruments that are in place for the thematic priority areas, that is the LSPs and other programs. The other was to start a 'New Nano Program' which was to consist of three parts. One would be the funding of infrastructure, the expertise areas, other curiosity driven research and fundamental research in the thematic areas. The second would be materials research and the third integration. Integration was proposed to deal with the interaction of "new generations of functional, smart materials that interact with the outside world" (p. 37) such as sensors, actuators, electronic components, optical or biomedical components. Diagram 8 shows how the organization of nanoscience and nanotechnology research was visualized in the report. The working party considered NANOMAT a good candidate to extend in the direction of the proposed program, but it stressed the differences with the proposed program by giving it a new name. (p. 38)

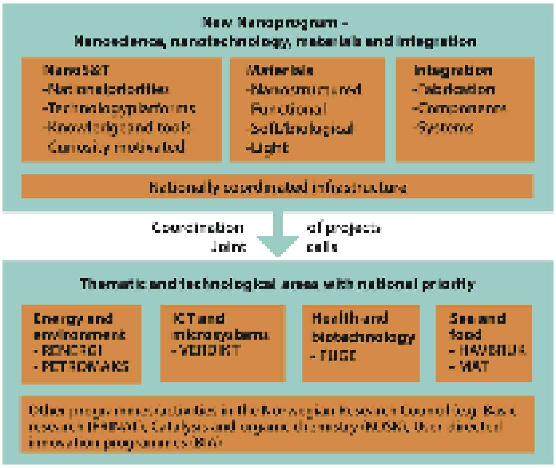

Diagram 8: Visualization of the New Nanoprogram, proposed by NFR's working party for nanoscience and nanotechnology.

Source: NFR (2007b, p. 37)
(Reproduced with permission)

It realized that the entire proposed strategy would require coordination with the existing programs at NFR and pointed out the necessity (p. 4, 20, 37). It also realized that the division of labor between the research funded through the New Nano Program and the research funded through the existing NFR programs required coordination. Therefor, it proposed that NFR established a coordination group which operates across all divisions and programs to coordinate all nanotechnology, nanoscience and materials technology. Moreover as a long term provision, the working party suggested to consider the option of creating a 'national council' for coordination of nanoscience and nanotechnology in Norway. This council should be linked to ministries and would be similar to the already existing Hydrogen platform. (p. 37)

Government response to the *National Strategy for Nanoscience and Nanotechnology*.

The Norwegian government welcomed the *National Strategy for Nanoscience and Nanotechnology* as an advice from NFR, but has not adopted it. As one interviewee pointed out, it is a national strategy but not a political. One reason for not adopting it was that it is rather broad and stretches outside the domain of NFR into societal areas. One such domain is environment, for which Norway has a Ministry of the Environment and related institutions. There was however little communication between NANOMAT and that Ministry.[307]

Another reason for not adopting the national strategy as a Government strategy was that adopting it would have important effects on budget matters. The Ministry of Education and Research also had to balance this nanotechnology proposal to proposals for different fields, such as humanities and health research.[308]

Still, the plan was welcome, for other reasons. The Ministry does not have the capacity, the staff necessary to develop plans like this. For the development of the next White Paper, the nanotechnology plan and similar other plans were considered a valuable input. Another reason why the plan was welcomed was that it was accompanied by scientific approval, organized through NFR. To the Ministry, the plan shows a prioritization made by researchers. This had at least two uses to the Ministry. One is that plans like this provided a basis to argue for additional budget when the Ministry participated in government wide budget negotiations. Secondly, if additional money becomes available, because of the scientific basis or because of other reasons, then there are plans ready.[309]

NANOMAT phase 2

NFR responded to the working party's advice through a follow up on the NANOMAT program, which it also named NANOMAT or NANOMAT phase 2. This renewed program broadly and explicitly followed the structure and categories of the *National strategy for nanoscience and nanotechnology* (hereafter in this subsection referred to as 'the strategy'). This meant that the same thematic areas, sub-areas, expertise areas were identified and that the strategy's proposed structure for laboratories and equipments was copied.

NANOMAT phase 2 however deviated from the strategy. It made a far more explicit choice to reorient from funding basic research towards applied research and integration in final products. Regarding the latter, the program noted a "knowledge gap" (NFR, 2007c, p. 3) with laboratory results. In the first

[307] Interview with H. Hvatum, L. Haaland and C. Gjersem.
[308] Interview with H. Hvatum, L. Haaland and C. Gjersem.
[309] Interview with H. Hvatum, L. Haaland and C. Gjersem.

NANOMAT program about 20% of the total budget was allocated according to plan to innovation driven projects. NANOMAT phase 2 was to shift the balance between researcher driven and innovation driven allocations to fifty-fifty (p. 15). In addition, the program aimed to increase contributions from industry in innovation driven projects from NOK 1,4 to 2 per NFR invested krone.

This stress on application and innovation was also one of the differences phase 2 showed with the first NANOMAT program. Contrary to the first NANOMAT program's brochures, the new work program did not explicitly define nanoscience and nanotechnology and spent only a few words on what it is about: "Nanoscience and nanotechnology (nanoST) is about deliberate control of materials and processes on the molecular and atomic levels." (p. 3). This leaves materials research out of focus and thus also on this level the new program moved its focus away from materials research.

Another difference with the first program concerns the selection of fields. Whereas the first NANOMAT program aimed to develop Norwegian research to an internationally high level and selected broad nanotechnology fields, such as nanomaterials, bionanotechnology, and nanoelectronics, the second phase aimed to prioritize those areas that in 2006/2007 still needed to be developed (p. 8). Its work program prioritized the thematic areas from the strategy as follows: 1) energy and environment; 2) information and communication technology including micro systems; 3) health and biotechnology; 4) ocean and food. This order was based on "national advantages in resources, industry or expertise" (p. 13). The work program noted that the Norwegian research institutes had prioritized nanotechnology in strategy plans and budget allocations and listed the prioritized activities of NTNU, the University of Oslo, the University of Bergen, SINTEF and IFE. NFR also had inventoried which companies were working on nanoscience, nanotechnology and new materials in the four thematic areas.

NANOMAT had transformed in line with the Ministry of Education and Research's prioritization of nanotechnology, and in line with the aims of the LSP instrument. Because of the shift towards user driven research, NANOMAT phase 2 was an unexpected step back for FUNMAT which had aimed for funding of basic research[310].

[310] Interview with H. Fjellvåg.

8.5 Concluding: dynamics of shaping and reshaping nanotechnology

The main conclusion of this chapter is that resource dependence not only is about a process of RFOs responding to changes in their resource situation, as the Dutch chapter highlights, but also that RFOs in this process shape and reshape nanotechnology as created through funding programs. Prioritization of a new field is not a one time occasion, but an ongoing process in which NFR develops its priorities in interaction with actors both in research and in government.

To the actors, it means that programs and priorities may develop in unintended ways. NFR saw itself forced to adopt materials research as a priority which it earlier had refused. It merged the field with its nanotechnology plans. With NANOMAT phase 2 it further changed the nature of the program, in line with the aims of the LSP instrument, which meant a phasing out of attention of basic materials research. This was not what the FUNMAT consortium had expected of the program.

The process is not only driven by major or sudden changes in NFR's environment, such as FUNMAT's lobby and the evaluation of NFR in 2001. Some, such as annual budget negotiations and the publication of the Ministry's White Paper are normal procedure and highly regulated. Whereas NFR did not prioritize nanotechnology in its 2004 strategic plan, the Ministry did enlist it in combination with materials research in its 2005 White Paper. To NFR, this was a trigger and legitimation to launch a working party to develop a national strategy for nanotechnology. This resulted in a proposal for a completely new funding approach to the field.

NFR did not follow this advice but further developed the program in tune with the Division for Strategic Priorities' mission and within the LSP frame that had been developed since the launch of the instrument. Thus, a new business-as-usual had set in and it gave nanotechnology its next shape.

Thus, not only the organizational shape of NFR, but also ongoing interactions with government and researchers, shape and reshape the way funding programs outline the field of nanotechnology and fill it with resources.

NFR's subsequent steps were not radically different from previous steps and from other actors' attempts to shape the priority of nanotechnology. This can be explained by strong interdependencies between NFR, the Ministry and researchers. Actors who have an abundance of one type of resource cannot dominate priority setting, because they lack others. The Ministry of Education and Research may have an abundance of financial means, it lacks the capacity to develop detailed plans for potential research priorities. It needs researchers who have an abundance of ideas and who provide scientific quality evaluation. It needs NFR to aggregate ideas, develop priorities and manage the priority programs.

In Norway, the situation is different from other countries because it has a one-council-system, which means that researchers have few other options to acquire funding. In addition, Ministries are inclined to channel their targeted funding programs through NFR and in particular the Ministry Education and Research supports NFR's central position, as is indicated by its reinstating of NFR's intermediary position directly after that was compromised by FUNMAT's successful lobbying. Because of the constellation and the strong interdependencies, actors cannot deviate too much from others, because they would risk loosing support.

8.6 Figures of the Norwegian case

Table 8: Overview of incomes and budgets of the Norwegian RFO, and the programs NANOMAT, FUGE and NORKLIMA 1998 - 2007 (x 1 000 000)

<table>
<tr><th></th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th></tr>
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<tr><td>• FUGE budget[313]</td><td></td><td></td><td></td><td></td><td colspan="6">906</td></tr>
<tr><td>• NORKLIMA[314]</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">345</td></tr>
</table>

[311] Source: NFR annual reports
[312] Source: NFR (2007c, p. 7)
[313] Source: NFR (2007a, p. 2)
[314] Source: NFR (2008, p. 2)

9 Comparison and Conclusions

We are now in a position to compare the four case studies of responses by RFOs to emerging nanotechnology, and draw further conclusions. A simple starting point of taking nanotechnology as an external pressure - and opportunity - to which RFOs can respond in different, or perhaps similar ways, is not possible, because nanotechnology is still 'under construction', and responses by RFOs will co-construct nanotechnology, at least at the national level. Therefore, Section 9.1 starts with the first of the four challenges identified in Chapter 1, and continues to discuss the other three.

The findings from this comparison, particularly the observation that RFOs tend to use existing instruments and approaches to respond to nanotechnology, leads to the next step. Given the gradually evolving web of resource dependencies in which RFOs are entangled, there might well be a general pattern in their responses over time. The extended resource dependence theory developed in Chapter 2 can explain this pattern, where at least at first, RFOs show a remarkably steady business-as-usual approach towards the field of nanotechnology. In that sense, the effect of a newly emerging field on an RFO is limited. Eventually, resource distributions and accompanying expectations of all actors involved can, but need not, develop into 'full-scale' institutional renewal. The question addressed in the third section is whether RFOs should be content with the present pattern of limited change, or go for renewal, with the risk of succumbing to the latest science and science policy fashion.

9.1 How have the challenges been addressed in the different cases?

Given the similarities in the organization and context of RFOs, I am interested in similarities across the cases. If these occur, and they could be understood in terms of (extended) resource dependency theory, general conclusions can be drawn about the response of RFOs to newly emerging scientific/technological fields like nanotechnology. Such an analytical strategy has to assume that nanotechnology is somehow given, while in fact, it is a matter of co-evolution or co-construction. Already in terms of resource dependency theory, responses of organizations are determined by their enactment of the environment, not by the changes as such, whatever these might be. In the case of nanotechnology, and of newly emerging sciences/technologies in general, there is an additional issue: such fields are still under construction, and their construction is partly determined by what actors, including RFOs, do.

Thus, the analysis of the case material has to start with inquiring how RFOs have been co-constructing nanotechnology as an emerging field. After that, this section continues by discussing the two major challenges that nanotechnology appears to create for RFOs, viz. the field's interdisciplinary character which may not match RFOs' disciplinary divisions and instruments, and the field's requirements for expensive equipment and facilities. The fourth challenge is of a different character. In nanoscience/nanotechnology, traditional distinctions between science and technology, and between the quest for basic knowledge and the desire for social relevance, become blurred. This is a challenge for traditional RFOs, but as discussed in Chapter 2, and exemplified in the national case studies, institutional changes have occurred to broaden the tasks of RFOs. The response of RFOs will thus be predicated on how earlier and ongoing institutional changes have developed in this direction. In other words, I expect to find differences, rather than similarities.

A field under construction

A gradual build-up of interest in nanotechnology as an emerging field occurred in the course of the 1990s, at the side of researchers as well as with the RFOs. Responses were also gradual, in the sense that existing approaches and instruments were sufficient. Three main ways of picking up on the new opportunity occurred across the cases, while one or the other is more clearly visible in one case than another.

One way is the is the tried-and-trusted responsive mode. If the RFO receives many proposals in a certain area or under a certain label, then that will be a newly emerging field and can thus be recognized as such. The Swiss NFP 36 was funded through a bottom-up program instrument and researchers applied for a nanotechnology program who were closely related to inventors of the scanning tunneling microscope. They wanted to continue research with scanning microscopes and applied for funding. Towards the end of the 1990s, RFOs in the Netherlands also identified nanotechnology through bottom-up applications and by enacting and analyzing their respective research environments. Through such bottom-up procedures and instruments researchers put the field on the agenda and researchers presented themselves as the experts of the field.

Another way was more atmospheric. Nanotechnology was 'in the air' and actors paid attention to it. This is documented for the 1997 nanotechnology program in Finland. There had been an EU foresight workshop, a personal interest, and meetings with others. Thus, signals originated from others, abroad and within the country, who had been interested as well. Earlier efforts, in various countries, to put nanotechnology on the research and research funding agendas had started to build up to nanotechnology being 'in the air'.

Gradually, as nanotechnology became recognized, it also became easier to identify the experts, and the experts knew who else were experts in the "world" of nanotechnology. If RFOs want experts as program managers, these can now be identified, cf. Norway and Finland. In general, program mangers, through their further environment enactment, can become more and more knowledgeable about nanotechnology and about nanotechnology activities in their country.

A third way emerged when nanotechnology was put on the political and funding map, in particular after the Unites States launched the National Nanotechnology Initiative in 2000. Now, an argument to launch a program could be that other countries or organizations were doing it and that one should not fall behind. Examples are the FinNano program at the Academy of Finland and FOM's initiative around 2002/2003 to take inventory of nanotechnology because others were investing.

Even while the field was still under construction, RFOs could respond, as long as they could rely on a global reference to nanotechnology. And there was no need to consider special treatment. This is what is similar across the cases, even while there are, of course, national specifics in the responses.

With the build-up of interest in the 1990s, it was necessary to become operational, and that is where variety is visible in how nanotechnology was defined and bounded. Interestingly, this was not felt as a major problem. Although there were attempts to create authoritative definitions at the policy level, RFOs were happy to work with definitions and boundaries that suited their purposes. There was borrowing, and occasional reference to alternative definitions, but clearly no need to conform. In terms of extended resource dependency theory: definitions are a way to mobilize and sustain resources, and will be adapted to that purpose.

This is clear for Switzerland, where two notions of nanotechnology coexisted. One referred to individual localizability of atoms and molecules, and was clearly related to the experimental methods enabled by the scanning microscopes, which were invented in Switzerland. It was used in NFP 36 and in NCCR Nanoscale Science. The other notion focused on so called top-down nanotechnology and positioned nanotechnology as an enabling further development of microsystems technology. This was related to the Swiss research and industrial traditions in the field of microsystems technology. It was visible in MINAST and in the NanoTera program.

The Norwegian NANOMAT program initially focussed heavily on materials research, a result of the FUNMAT lobby. In NANOMAT's second phase, materials research, although still considered important, had a less dominant role. In this particular case, it was related to the shift, in the program, from basic research to a fifty-fifty distribution between basic and applied research.

In the Netherlands, different NWO divisions STW, FOM and Chemical Sciences in their respective nanotechnology activities focussed on different disciplinary foci. In the NanoNed program the notion of nanotechnology with a focus on individual localizability was quite visible, next to manufacturing and materials. The recent Blank Committee, for its own good reasons, viz. capturing as many human resources as possible, pushed a non-specified, 'umbrella' notion of nanotechnology. The Swiss TOP NANO 21 program used a non-specific notion in order to prevent discussion about it.

Tekes and the Academy of Finland, after heaving used a shared notion of nanotechnology in the late 1990s, used diverging notions five years later, when they stressed their respective positions on either side of the science-technology divide.

Why this variation, and why does it continue? Resource dependence theory in combination with boundary-work theory as developed in this thesis, offer explanations.

Let us start at the research side. Researchers perform boundary work[315]: they outline a particular field of research and attribute characteristics to it, in order to mobilize resources for the field, which they then will be able to profit from since the definition favors what they want to do themselves. This is a general strategy, also visible in the struggle for industry standards in a sector of industry. The variety of local and national resource contexts thus feeds the variety of definitions of nanotechnology, and makes it difficult for a shared and authoritative definition to emerge.

It is only at a later stage, when boundary issues have to be settled, that standardization becomes an issue. For the industrial application of nanotechnology, there is already such a need, and OECD and ISO have working parties to define nanotechnology. Competition for a dominant definition is then the explanation for non-stabilization of the definition of nanotechnology.

RFOs have their own changing sets of aims and resource dependencies and this has effects on how they frame funding programs, including the topical definitions such as the definition of nanotechnology.

The arguments given for delimiting nanotechnology in particular ways often are of a practical nature. Such as, if we do not apply the functionality criterion

[315] At least, this is what the theory of boundary work claims. The chapters do not document the actual proposal, but the eventual programs, which, as is discussed elsewhere in this section may undergo one or more translations.

then all chemists can apply, or, if we do not limit the program to 100 nanometer, then all microtechnologists can apply. The point of these examples is not that the RFO does not want to fund chemists or microtechnologists. They may have funding opportunities for chemists and microtechnologists and they see that chemists and microtechnologists can do nanotechnology. Budget requirements however do not afford the RFO to be too lenient, so a line is drawn at 100 nanometer.

Although nanotechnology continues to be a field under construction, RFOs did not perceive this as a problem, and need not do so because business-as-usual approaches appeared to be adequate. This is linked to the field's open character, so that a program can be shaped as an RFO or researcher sees fit.

An RFO's remit and/or disciplinary focus guides such further specification when it comes to developing funding programs for the field. Practical arguments about inclusion or exclusion of certain groups of researchers may play a role in further sharpening or opening the demarcation of the field. If, alternatively, researchers propose programs, their background and research agendas guide further specification of the field. Examples here are the Swiss NFP 36 and the NCCR Nanoscale Science.

Thus, ongoing dynamics of resource distribution and demands and expectations that guide availability of resources prevent full closure of the definition. Still, two kinds of stabilization can result. The first kind is that the existing landscape with its historically developed emphasis on some fields or groups of fields, may have a stabilizing effect through which some national closure may occur. This is visible in Switzerland where a focus on individual manipulation of atoms and molecules and a focus on microsystems and microelectronics exist and resulted in two definitions of nanotechnology which are dominant in research funding.

The second kind of stabilization is the continued use of nanotechnology as an umbrella term. Defining or outlining the field is not necessary, as in the Swiss TOP NANO 21 program and the Dutch Blank Committee report, so that a variety of human resources can be captured, at least at the policy level and resource mobilization levels. There is another aspect to the use of umbrella terms. Umbrella terms bridge science and policy and when they can be linked to societal relevance, they allow bidirectional flows of promises and resources between science and society. They can be invoked both by policy makers/politicians as well as by scientists and may become established before the field itself has become articulated – as is the case with nanotechnology. An important role of umbrella terms is that they can create a de facto governance effect, i.e. an organizing and shaping effect without explicit top-down steering. (Rip, 2009; Rip & Voß, 2009)

RFOs, operating between research and policy-making, can use such umbrella terms to mobilize resources from both sides. In addition, it can use the umbrella term to effectuate coordination without recourse to an explicit steering role or steering rhetoric, while still modulating the field to its own purposes or for practical reasons. Thus, there might actually be effects on ongoing research, in spite of the global (umbrella) character of nanotechnology.

The Swiss chapter presents a graph of the number of 'nano'-labeled projects, including an increase in the late 1990s, that is, before the US NNI, but after the first two nano-labeled programs had started in Switzerland. So, apparently researchers had reasons to use the label. There can be different reasons for the labeling, but even if it starts as a strategy to exploit funding opportunities, it can have effect on the research agendas of research groups. (Dits, 1988; Saari & Miettinen, 2001)

An interdisciplinary field challenging disciplinary divisions in RFOs

Part of the umbrella of nanotechnology is its interdisciplinary character. RFOs can't help but fracture the field, because they have to treat it through their disciplinary organizations or divisions, which each limit their dealings with the field to their respective disciplinary borders.

This is what I would expect: a disciplinary RFO or division has other disciplinary 'neighbors' and through their resource needs they keep each other in check. If a division would finance substantial amounts of projects or research too far outside its field, researchers from within the field would complain and might be less inclined to provide their kind of resources to the division. In addition, other divisions may complain because the 'invading' division could hamper policy plans. Researchers from the other divisions' fields will not complain because to them a new source of funding becomes available. They then become less dependent on their division, which is a change in the distribution of resources which in turn may render policy plans from other devisions less effective. Because the neighboring division can also counter-invade the invading division's field, the divisions take each other's policy plans into account. Thus, unless the divisions find ways to cooperate and see reasons to cooperate their joint constellation of resource dependencies limit their interdisciplinary room for maneuver.

This fracturing effect is visible, but only occasionally and in particular for the Dutch NWO. In 2000, its Chemical Sciences Division identified molecular nanosciences as a new priority area. From the priority's title and the short description provided in the chapter, a particular focus on individual molecules was in place. A few years later, FOM, NWO's division for physics prioritized the area of 'Nano physics / technology', indicating a preference for the physics parts in nanotechnology. In both cases, the actors involved did see that nanotechnology was broader and had broad fields of applications, but still their priorities were limited to the borders of their disciplines. Similar fractioning is also visible in the programs of the Swedish foundation for Strategic Research.

Why would there be so few more examples? Two, not exclusive explanations can be offered. Firstly, in the other countries and in the Netherlands as well, funding programs were identified and developed outside the RFOs' disciplinary structures. At the Academy of Finland, targeted funding programs are launched by the Board, which represents all the disciplinary divisions. In Switzerland, SNF's disciplinary divisions do not launch targeted funding programs, neither does SNF's board. There, a separate division next to the disciplinary divisions handles the NCCR and NFP funding programs and handled the SPPs, but does not develop them. In Norway, NFR's Division for Strategic Priorities, one of the then newly established functional divisions, launched the NANOMAT program. So there was no pressure on the (traditional) RFO.

The second explanation for there being only few examples of fractioning is that disciplinary divisions could cooperatively developed programs for nanotechnology. This happened to a nanotechnology program which was developed by two NFR disciplinary[316] divisions before 2003. Within the Dutch NWO, divisions cooperated on two occasions.

A complementary question is whether programs developed outside of RFO's disciplinary structures, still succumbed to disciplinary divides. .

The 1997 nanotechnology program of Tekes and the Academy of Finland deliberately did not subdivide nanotechnology at all because the managers wanted it to remain open to proposals from different disciplines. The Swiss TOP NANO 21 program also did not use a subdivision, in line with its open approach towards the definition of nanotechnology.

Some programs used functional rather than disciplinary subdivisions. The FinNano program of the Academy of Finland is an example. It consists of 'Directed self-assembly', 'functionality in nanoscience' and 'properties of single nanoscale objects'. Also the Swiss NCCR Nanoscale Science was structured partly by modules on 'atomic and molecular nanosystems' and 'functional materials by hierarchical self-assembly', next to 'nanobiology' and 'quantum computing and quantum coherence'.

Funding programs developed outside RFOs' disciplinary structures can still refer to disciplines. Tekes's FinNano program, NFP 36, NANOMAT and NanoNed were all developed outside national RFOs' disciplinary structures and all use known disciplines and sub-disciplines focussing on the nanoscale.

[316] At least, one was a disciplinary division, the other was a half thematic half industrially oriented division.

So, while it is institutionally possible to ignore disciplinary funding structures, actors still adhere to existing disciplinary categories to structure a nanotechnology program.

At NFP 36, the program developers felt that one cannot simply start with new categories, but has to prepare the ground by acquainting the existing disciplines with the new field. The developers of Tekes's FinNano structured the program while keeping in mind existing parties and activities. So did the Blank Committee in the Netherlands when it developed its subdivisions. Also, programs' subdivisions are related to research activities, that is existing resource dependencies, that already exist within a country. Or, within a location, as the NCCR Nanoscale Science is structured in line with specialties locally available.

Thus, RFOs' disciplinary divisions fracture the field, whereas instruments launched outside the field may still be fractured because they reflect subdivisions important in the national research landscape. This may explain why I found no signs of researchers protesting to the RFOs' fracturing of the funding programs.

Definitions and subdivisions of the field for funding programs are thus largely dependent on the research landscape and the research funding structures, which also reflect that landscape, thus on earlier investments and priorities of RFOs, ministries, universities and public research organizations.

Facilities and equipment

Nanotechnology has strong requirements for equipment and facilities. It is more distributed, and does not require the same long-term planning as in high-energy physics with its accelerator facilities, but it does require sustained investment and coordination of use.

Existing national structures and procedures of distributing resources make it difficult to integrally target the field of nanotechnology including its demands for equipment and facilities. In general, ministries for science and education provide institutional funding which the universities and research organizations can use to invest in equipment and facilities. Occasionally or on regular basis, Ministries or RFOs have separate equipment funding programs and they are an opportunity for researchers.

Leaving aside the details[317] such a system can cover nanotechnology's and other fields' needs, but it has a drawback. Equipment programs are general, they have a bottom-up open competition, and compare proposals from different fields against each other. Part of the evaluation may be the alignment of the

[317] Who finances running costs? Who takes financial risks? Do the different schemes together leave particular funding gaps of equipment that is too expensive for one funding instrument but too cheap for another?

proposed investment with other investments or priorities which leads to an indirect comparison of priorities across those fields or disciplines that are represented in the proposals.

What often happens, is that the burden of solving the problems of the national constellation of funding of research ends up at universities and research organizations. Depending on the exact arrangements, universities and research organizations can be well off and simply acquire what they need, or the system works well enough for relatively modest plans. It may however require entrepreneurial skills to finance local plans for new fields of research (Robinson, Rip et al., 2007), bringing together multiple sources for funding, possibly including private funding.

Occasionally, researchers do not put up with the existing system after initial attempts to finance their plans failed. They increase pressure on the RFOs by addressing Ministries directly and argue that nanotechnology, or materials research as was the case in Norway, is important enough for a different approach and substantial funding.

Such researchers maybe successful or not. In the case of FUNMAT in Norway and the consortium of three in the Netherlands they were, but had to accommodate to broader considerations. They were successful in finding larger sums of money needed to finance their initially local ambitions, but the Ministries widened the focus to the national level. They were willing to provide the requested larger sums but they also felt that other researchers with similar interests should have the possibility to benefit as well. Thus, through the entrepreneurial work and funding requirements, local and national priorities become connected. The Swiss NCCR instrument made such alignment a main target. Of all programs discussed, it is the only bottom-up instrument that addresses this issue and allows investments in equipment and facilities.

In the Netherlands, because the Government aimed for investments in knowledge infrastructure, the researchers of the NanoNed consortium were able to design an R&D program which not only involved a range of project funding instruments, but also a set of investments in equipment and facilities in the three main locations.

In Norway, NFR was in the process of developing a funding program instrument to stimulate strategic priorities, which took aspects ranging from basic research to product development into account. Although this instrument did not allow for large investments it did cover smaller scale investments in facilities and equipment and could also integrate that into the program.

Financing equipment and facilities is subject of resource distributions which delegates the main problem to research performing organizations. When nanotechnology is concerned RFOs' program funding instruments are not geared to, say, 'suite funding' of nanotechnology including demands for funding of equipment and facilities[318].

Societal demand for closer relations between industry and research

Most, if not all funding programs for nanotechnology discussed in this thesis have to deal with the issue of nanotechnology's relation to industry and economic development. This is not only a matter of overall promises, sometimes as grandiose as a next industrial revolution. There is also a strong design orientation in nanoscience research, and start-up companies are established building on findings in public laboratories. In what way do RFOs respond to this challenge? Some programs, like NFP 36 and the FinNano program of the Academy of Finland, address the potential and the promises of nanotechnology as part of the legitimation of the program's existence. Others, such as TOP NANO 21 and NanoNed, in addition address the issue in research projects.

In general, RFOs are very much determined, that is both enabled and constrained, by their history, and by earlier, general, attempts to cross divides between science and technology, and between science and society.

As argued in the introductory chapter, the trend of changing societal demands regarding the relation between research and industry is not a recent trend. It has been going on for at least three decades. Moreover, governments and researchers have been responding to pressures to establish closer relations between research and industry. In all four countries a science-technology divide was created.

Finland and the Netherlands launched technology RFOs in the 1980s. Switzerland and Norway already had such RFOs as of the mid 1940s. The introduction of technology RFOs created a science-technology divide in the national research funding structures. The Finland chapter showed that attempts to bridge that divide were limited by differences in resource dependencies and related practices of environment enactment and program development between the two types of RFOs.

Whatever researchers wanted to do, as far as RFOs were concerned, they had to address either one or the other type of research. Researchers would therefore choose to focus on one of the two. While they could choose on project by project basis, they could also specialize. But the divide at RFO level was not an incentive to continuously bridge the divide.

The science-technology divide thus provides an explanation why some programs, such as the FinNano program of the Academy of Finland, respond to

[318] SNF's NCCR instrument and NFR's LSP instrument do so to some extent.

the emergence of nanotechnology by legitimizing the program in economic terms as well as scientific terms, but then in its project instruments has no particular requirements about economic or other societal relevance. On the other side of the divide, Tekes FinNano program does require the nanotechnology projects to develop a new functionality which may improve products or production processes and to involve companies.

For programs developed outside science or technology RFOs, viz. NANOMAT, NanoNed and TOP NANO 21 it was easier to go for a balanced approach to basic research and to technology development. TOP NANO 21 even required both types and application development to be addressed within individual projects.

Overall, emerging nanotechnology did not trigger further attempts to bridge the divide. If these occurred, as in Finland, they were part of a general move to better manage the relations between research and industry. In a sense, in all countries it had already been a challenge to do this, and the partial solutions that had been realized were now also applied to emerging nanotechnology.

What did happen is that nanotechnology was welcomed as an opportunity for strategic priority setting. Such priority setting in relation to program funding works out in different ways in the different countries. And when there is a special unit or division, as in the Norwegian RFO, it will actively look for possible priorities. I will briefly outline the situation in various countries, so as to indicate how nanotechnology could fit in.

In Finland, the Government does not involve itself directly in the selection of RFO funding programs, neither on the science side, nor on the technology side. RFOs on both sides of the divide are however aware of their societal role and they take that into account in the topic selection of their funding programs. They keep in touch with their respective Ministries through regular meetings and the spring meetings for budget negotiations. From the side of the Ministries, they involve program managers when issues like equipment funding are to be decided upon. This appears to work well.

In Switzerland, the science-technology divide is linked to a division of authority between Federal Council and the Cantons. The Federal Council is the widely acknowledged authority to participate in the say, political selection of program proposals, while SNF is the accepted authority to provide feasibility evaluation and organize scientific peer review.

Norway has a similar division of labor as Finland, except that the activities of the new Division for Strategic Priorities in RCN became related to the process of the Ministry of Science and Education's priority settings. They each developed similar but not the same lists of priorities, and took turns suggesting alterations to the other's list.

To strategic divisions and also to strategic RFOs such as exist in Sweden and Denmark, a new field of research is an opportunity to show what they can do, and thus legitimates their existence. It is a resource, both practically and symbolically. This is visible in how monitoring of developments and environment enactment by strategic RFOs or divisions of RFOs is oriented towards identifying new fields and their industrial/societal potential as early as possible.

A first-round conclusion - responses are shaped by a web of resource dependencies

While the similarities and differences between the cases show a complex picture, what is shared is how RFOs are embedded in a web of resource dependencies, which slowly evolves but can occasionally undergo a shift. Such embedment makes for inertia in the face of possible change. A newly emerging field like nanotechnology is then approached in terms of institutions and processes that are already in place. This may be seen as somewhat limited, as turning it into just business-as-usual, but it has definite advantages in terms of exploiting resources, utilizing resource dependencies as an intermediary organization. One can still call it institutional inertia, but there is a rationale to it, at least at first. I will return to this point in the next section.

Here, I want to emphasize that the nature of the responses of RFOs are instances of a general phenomenon, as it is characterized by the extended resource dependence theory. I was able to make the developments understandable in terms of this theory, and to support my point about it being a general phenomenon, I will briefly sketch other responses of RFOs, in particular to structural changes in resource position. This is an excursion compared with the main line of my argument in this concluding chapter, but it is important to pursue it briefly to show the value of resource dependence theory, if extended, to understand intermediary organizations.

There are structural changes in financial resource distribution when the situation of universities and research institutes changes, for example due to ministerial budget cuts, or because of developments in student numbers. The latter happened in Norway in the 1990s, which partly explains NFR's strong position in the Norwegian research landscape. Recently, in the Netherlands, the Minister of Education, Culture and Science re-routed € 100 M from the budget for universities to NWO.

Such changes which reroute financial resources from universities to RFOs will improve the RFO's position. In particular, RFOs with a strategic role or a steering function will welcome such a change, because they can exert more influence on researchers and their institutions.

There is also the general wish to be the key funding institution in the national landscape, not just because of the amount of resources that would be available, but also the sort of monopoly, and thus control, that would come with it. In the Netherlands, this is visible in the recurring rhetorics of NWO, for example in relation to the BSIK (ICES/KIS) funding scheme. It feels bypassed,[319] and I have discussed examples for nanotechnology. NWO's new chair, J. Engelen, went into the offensive when suggesting that the BSIK budget should simply be added to NWO's (Van Overbeeke, 2009, p. 6).

In countries with a multi RFO constellation, such as Sweden and the UK, the separate RFOs are used to a situation where they can be influential only in a particular field. In addition, when both sectoral and disciplinary RFOs exist, they may be used to cooperate, or at least coordinate.

These observations about the national level of RFOs' focus set the scene for a brief discussion of the response to European research funding opportunities as provided by the European Science Foundation, the European Commission's Framework Programs and the recently established European Research Council[320]. ESF uses an opt-in system for national RFOs to participate in individual programs, and has little financial resources of its own. The Framework Program has such resources, and these have increased in volume[321]. It aims to strengthen the EU's scientific and technology base for industry, international competitiveness, and social cohesion and cultural diversity. The ERC is important, independent of the size of its budget, because its grants are spent on individuals. A number of RFOs have similar instruments that reward individual, actual or potential, excellence.

Clearly, the resource position of national-level RFOs is changing. They do not appear to see it as a new dependence, for example because researchers may now shift to other funding sources, but rather as an opportunity. This is particular clear for the EU Framework Programs, which for the national RFOs, constitute an arena of competition rather than of detailed coordination.

National RFOs' orientation towards national interests is understandable from their intermediary position between national ministries and national researchers. They are geared to coordination of investments over a national group of researchers. When they are part of international coordination, they become the coordinated and in addition their coordinators are not their funding ministries.

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[319]A recent evaluation of NWO pointed out its week position in basic application oriented research and literally referred to 'bypasses' (Van der Vliet, Bensing et al., 2008, p. 29 - 31).

[320] The ERC is financed through the currently running 7th Framework Program, but distinguishes itself from the Program's aims because it finances basic research rather than applied or application oriented research, and because it finances individual researchers instead of international research consortia as the bulk of FP instruments do. The ESF has complex cooperative programs in which national RFOs decide to invest or not. The Framework Program is not an RFO but a program.

[321] From around ECU 3 750 M for a 4 year period to € 50 500 M for a 7 year period. The number of participating countries has increased as well. (European Commission, 2007, p. 6; Guzzetti, 1995, p. 84)

Thus, it is understandable that the nanotechnology programs discussed in the preceding chapters show few signs of deliberate alignment with European programs. Given the aims of the FP instrument which overlap with the way nanotechnology is positioned, this might be considered surprising. Similarly, program brochures may refer to activities in other countries, but these are used to legitimate national investments rather than coordinate. National investments were made based on strong developments and capacities within the country, not on opportunities and weaknesses resulting from an international comparison[322].

9.2 A diachronic pattern in the response of RFOs to nanotechnology

There appears to be a pattern in the responses of RFOs to emerging nanotechnology, in which four stages can be distinguished. These stages build on each other, because the web of resource dependencies evolves, partly because of the actions and interactions in an earlier stage. Thus, there is cumulation from an early encounter with nanotechnology, to addressing the requirements of the emerging field, to perhaps attempts at institutional transformation of the RFO. The four-stage model is of course a reduction of complexity, but it is a productive reduction. It is related to what was encountered in the case studies, and what is arguably plausible in terms of the extended resource dependency theory. It is also productive because it raises further questions, in particular about the apparent institutional inertia of RFOs. I will reflect on this in the final part of this section.

[322] One exception might be Finland, where it was acknowledged that Finland could not play a leading role whatsoever in nanotechnology, but that it at least could develop the competence necessary to identify where in the world particular nano-knowledge can be found.

Stage 1: early developments: nano is around

Nanotechnology is an interest of a still limited number of researchers who apply for project funding. The emergence of nanotechnology becomes visible to RFOs through the use of the 'nano'-label by researchers, in the title or text of their applications. No special response from the RFOs is required. They can accommodate the emerging field through their open project funding instrument and funding programs that happen to accept nano-proposals. Nanotechnology's interdisciplinary character and wide range of possible applications allows proposals to go to a variety of programs.

An RFO or funding program will support nanotechnology only as far as their remit allows them. An RFO for chemistry will finance nanochemistry and a medical RFO will finance nanomedicine. The use of the label may be noticed, but as part of other fields, such as materials research, supramolecular chemistry or microelectronics. At this stage, RFOs do not enact nanotechnology as a new and promising field that they have to do something about. When the use of the label continues and expands, this may change. External events are also important here, like an announcement elsewhere that nanotechnology has been selected for special treatment. The USA National Nanotechnology Initiative, established in 2000, played such a role. In most countries studied here, this was additional to initiatives and some targeted funding that had appeared already, in the second stage of the pattern.

Stage 2: a promising new field is recognized

Increasing numbers of researchers have become interested in nanotechnological research, and there is reference to nanotechnology, as an umbrella term. Thus, what is now an emerging field comes to the RFOs' attention. Sometimes also ministries or government agencies acknowledge the field as promising or even of strategic value to the national economic and/or other interests. These actors, government as well as researchers, expect or demand that the RFOs address the field. Because they provide essential resources to the RFO, i.e. money, input and legitimation, the RFO is under pressure to do something.

Of course, there may be RFO-internal movements to recognize the emerging field, but these often need the external pressure to get a hearing. Basically, an RFO has two options: yield to the pressure, or not. If they do not take any action they may legitimate that by pointing out how much can be done, and is done, through business-as-usual. For example, they can look for the occurrence of the nano label in their funding portfolios and identify projects and programs that fully or partly address issues that fall within a particular definition of nanotechnology. In the UK, the Department of Trade and Industry and the research councils used such a strategy to fend off parliamentary allegations that it did too little too late. This starts as a continuation of Stage 1 response, but an account has to be offered, and this can lead to further questions and thus further pressures.

When RFOs yield to the pressures, say by launching targeted nanotechnology programs, they do so within the scope of their organizational remit and the existing types of instruments. So again a business-as-usual approach. This may result in fracturing of the field along existing disciplinary/sectoral divisions and along the science-technology divide. An RFO for physics launches a nanophysics program and if it is an RFO for basic research, it will likely launch a nano*science* program rather than a nano*technology* program, which is has to be launched by a technology RFO. Examples of this are Dutch STW's program 'Steps in the micrometer and nanometer area', NWO's Chemical sciences Nanochemistry program, and Finland’s Tekes' FinNano program.

Business-as-usual may allow a more integrating approach, i.e. crossing disciplinary borders, if instruments exist that afford it. Many RFOs have such instruments, which are outcomes of historical developments where ministries assign strategic roles to RFOs and an orientation towards societal issues which presumably are of interdisciplinary nature. Whether and to which extent RFOs used such instruments to address nanotechnology differed, but when they 'prioritized' the field it was with relatively small budgets compared to other priorities.

In other words, the web of resource dependencies entangled with institutions and demarcations determines the way the new field is recognized and to some extent taken up. This implies that responses will be conservative. Even so, there will be some action, and resource dependencies can change a little. These can accumulate, and opportunities will then arise for actors dissatisfied with the conservative responses to push for more pro-active approaches.

Stage 3: reluctant institutional change

Actors now insist on special treatment of nanotechnology. These may be researchers who find that existing funding opportunities do not meet their needs to further develop the field. These may also be actors within RFOs, as the history of the US NNI shows. Governments or ministries may benchmark national against foreign developments and conclude that novel measures are necessary. Not all these actors have discretionary power to release substantial additional resources. Ministries and government agencies – including the RFOs themselves – have such a position, and even then may not be able to release additional resources from one day to the other.

There are other ways to respond, however. There may be occasions to reorganize, and/or develop new types of instruments. These occasions may well occur outside RFOs, when governments want to create space for new and promising fields, particularly when there is a link to innovation. This is not triggered by the emergence of nanotechnology per se, but does create resources for it. Interestingly, it works also in the other direction: the new government programs and budgets must be filled, and so there is a need for fields like nanotechnology.

It is an empirical question how much of Stage 3 occurs in every country. Some of it is in place everywhere, however, and in particular, the active interest of other actors than RFOs. This puts RFOs in a difficult spot because it modifies or threatens existing distributions of resources and thus their intermediary position. The three types of responses specified in the extended resource dependence theory, can be found in the cases that were studied.

Firstly, continue business-as-usual. This happened in Denmark when the government launched a strategic council. The science RFO had not adjusted its mission to cover more than basic research because it did not want to lose or risk losing resource support from researchers. The risk of such a strategy is clear: the RFO loses its dominant or monopolist position, if it had one.

The second type of response is the shift to accommodate the external changes and pressures. An example is the Swiss SNF when it accepted the management of the NFP instrument in the 1970s and established a separate division for that next to its disciplinary divisions. Another example is the increased cooperation between Tekes and the Academy of Finland due to political pressure. They cooperated on their funding programs, but kept close to their respective organizational structures and practices of funding and environment enactment. A third example is how the Dutch RFOs, when bypassed by the third BSIK (ICES/KIS) round in which NanoNed was funded, initially responded to the change of resource distributions concerning nanotechnology by focusing on other fields or subjects that were not covered by NanoNed.

The third type of response occurs when RFOs strategically involve themselves in the external parties' demand articulation processes. This happened in the Netherlands in the RFO’s recent participation in developing a national agenda for nanotechnology. Another example is NFR's further development of the NANOMAT program into a design for a national nanotechnology research agenda.

Such responses, however reluctant, change resource dependencies, and thus create a new situation in which further shifts, even institutional transformation, become possible.

Stage 4: organizational change to address the challenges of nanotechnology

At the moment, this stage is somewhat speculative, because it was not yet visible in any of the four in-depth case chapters. However three examples can be identified where actors indeed proposed such changes.

The working party, launched by the Norwegian NFR in response to the Government's White Paper on research, proposed to radically change the funding approach of the field of nanotechnology in light of its broad interdisciplinary character and wide range of applications. It also proposed a body to coordinate nanotechnology in and across NFR's existing funding instruments. Thirdly, it suggested installing a national council, directly linked to ministries, to coordinate Norway's nanotechnology research. NFR did not initiate actions to follow-up on these proposals, however, and continued to finance and coordinate nanotechnology through the NANOMAT phase 2 program.

Another example of proposed organizational change triggered by nanotechnology could be the establishment of a dedicated division for nanotechnology, or participation in a dedicated consortium or *regie orgaan* (orchestration body) for nanotechnology. A precedent here is the Dutch *regie orgaan* on genomics, and the early discussions in the Netherlands after the *Kabinetsvisie* on nanotechnology was published in November 2006 indeed referred to it as a possible model for the organization of stimulation and coordination of nanotechnology R&D.

The third example is how the coordinating body Research Councils UK in 2008 formulated a program, across the councils, to address nanotechnology. It plans to cover basic research and application, including risk governance, economic issues and social applications, through interdisciplinary consortia jointly financed by six out of seven RFOs.

While such organizational changes are now on the agenda, it is clear that many RFOs find it difficult to make such a move, and break out of the business-as-usual mode. This is particularly the case for disciplinary-oriented RFOs. They represent and through their funding activities reinforce disciplinary differences in researchers' resource dependencies. Thus, the disciplines continuously keep each other in place and cause a conservative effect towards interdisciplinary new fields.

In the UK, the RFOs are more pro-active because of their specific history, being exposed to pressures to become strategic since at least the early 1990s. Scenarios for Stage 4 may materialize in the UK first (Cf. Rip, 2000).

Evolving patterns and structures

The successive stages as outlined here are not just driven by an externally given development of the field of nanotechnology and the related increasing and changing demands for particular resources, and offers of other resources. They show endogenous dynamics, linked to the nature and resource dependencies of RFOs, as each stage opens up possibilities for maneuver that allow - but not necessarily determine - the next stage. That is why the four-stage model tells us something about RFOs, what they can and cannot do when they need to respond to major scientific developments like the emergence of nanotechnology.

In the four-stage model, conservative organizational behavior is the first reaction, with reluctant acceptance of changes and only after cumulative developments, some willingness to consider larger institutional changes.

Extended resource dependence theory allows us to understand such conservative organizational behavior. Organizational structures, funding instruments, rules of proposal review, acceptable types of scientific and societal legitimation and shape(s) of the new field, are built in relation to, and embody, resource dependencies. They keep each other in place.

The theory also offers a means to understand how such institutions can change. There is the gradual accumulation of minor changes and shifts, including changes in resource dependencies. And there are external changes, related to the evolution of new fields, but also other resource changes, for example government-led shifts of resources and responsibilities from universities to RFOs. By themselves or together, these create openings for change. Sometimes, actors take initiatives and become institutional entrepreneurs. The build-up of pressures and/or changes in patterns of resource dependencies that require a response is another route towards change. And such changes may then stabilize and create new, temporarily stable business-as-usual approaches.

Are RFOs conservative organizations?

Those who identify with an emerging field like nanotechnology will position RFOs as conservative. RFOs have to go through the first stages, and then they are reluctant to enter into the fourth stage of organizational transformation. While one can *understand* why they behave this way – that is where extended resource dependence theory comes in – this cannot be a *justification* of their behavior. And in fact, there have been criticisms of RFOs in general, as being unnecessarily conservative. My analysis of RFOs as embedded, and thus imprisoned, in a web of resource dependencies, can excuse them, but does not imply that there are no other and better roles and paths of development.

The four-stage model of mainly reluctant change, and the present limited investment in the fourth stage, need not be a message of despair ("RFOs can't change"), however. Facing newly emerging fields, their reluctance to introduce major changes may actually be a sensible response, to avoid investing too much in what might turn out to be the latest scientific fashion. In another few years, it might turn out that nanotechnology was just a hype, or at best an umbrella term for various lines of research each of which can perfectly well be financed through the research funding instruments of the 1990s and 2000s, within the existing disciplinary RFOs and divisions. This may lead to insufficient funding of facilities and equipment needs, but even so, in a decade or two, it may be judged that in view of other research priorities and budgetary limitations, actually the best possible choices were made.

We cannot wait for another decade or two to see whether nanotechnology was mainly hype. Thus, there is an immediate question: when is a new field important enough to consider major organizational change to address it adequately? And the background question is about institutional inertia, or better, path dependency, where earlier investments in the web of resource dependencies enable and constrain further steps. What would be an occasion to attempt to break out of the path?[323]

What can we say about the new field? Nanotechnology is now very visible at the policy level, and research agendas and budgets are available. In their operationalization, nanotechnology gets fractured along at least three dimensions: disciplinary, science-technology divide and funding instruments. There might be resistance to this, if researchers think of nanotechnology as a more or less coherent field, worthy of support. But do they? Cf. how Schummer (2004) and I in my case studies heard no complaints about fracturing along disciplinary lines. A typical view would be that a bit of additional chemistry to what is essentially a physics project, is sufficient interdisciplinarity to the physicist, so she does not mind the fracturing. Perhaps interdisciplinary education in nanotechnology may raise a generation of researchers who will only settle for 'real' interdisciplinary approaches - the shape of which we cannot predict.

At the policy level, the pressure to address what are considered to be the challenges of nanotechnology continues, and actors interested in major change can refer to it (this is how the Norwegian NFR, or better, actors within NFR, came up with their ambitious proposals). If reorganization occurs, however, it will not be because of nanotechnology alone. Other, earlier, emerging fields, and other pressures for change have been configuring the web of dependencies, and the need to reorganize RFOs may derive from the wish to have them become more strategic. Nanotechnology is then the occasion for change, not the driver. Or perhaps a final push that tips the balance.

[323] Mindful deviation, a phrase introduced and discussed by Garud & Karnøe (2001).

The key question, now and at an earlier stage, remains whether the promises about the new field are mainly hype, or whether there is some substance underneath the hype? Instead of looking, possibly in vain, for early indicators, RFOs can opt for reflective action by investing in reorganization for such a new field, while monitoring what is happening with regards to expectations and whether they become more realistic. If not, the investment in institutional change should be withdrawn, which may be costly as well if the web of resource dependencies has meanwhile been reshaped.

Another approach is to muddle through, creating add-ons to address immediate problems. This is definitely how the Dutch response, by RFOs as well as the government, can be characterized. The add-on strategy is safe in the short term, but may be insufficient in the long term. By that time, it may have become clear that the organization has become unwieldy, and needs to be redesigned. As we know, redesign is not easy, but eventual challenges of nanotechnology (or of another emerging field, or of converging fields) may trigger it.

Clearly, the situation is more complex than was envisaged in the question I phrased at the beginning of this thesis: what is the response of RFOs to a newly emerging field like nanotechnology? Emerging nanotechnology is just one element in an evolving web of resource dependencies, including pressures from research and from government to change the institution. It is this web of resource dependencies which constrains, and also enables, RFOs in their activities and strategies. That is why RFOs, as intermediary organizations, are so conservative.

Having documented this, and having offered a four-stage model for evolving responses, I can now turn the tables. As I observed at the beginning as well, science and technology change all the time, and RFOs should be agile so as to respond adequately, particularly now that strategic considerations about science and technology are becoming more important. If RFOs are to adapt and sometimes be pro-active, they need openings to do so. Nanotechnology then can be seen as an opening, rather than a challenge to business-as-usual. The question then is how RFOs can and will use these openings.

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11 Abbreviations

Abbreviation	Country	Native name or description	English name or description[324]
CHF	Switzerland	Schweizer Franken	Swiss Franc
CW	Netherlands	Chemische Wetenschappen	Division for the Chemical Sciences
DKK	Denmark	Danske krone	Danish crown
EDI	Switzerland	Eidgenössiche Department des Innern	Federal Department of Home Affairs
ETH	Switzerland	Eidgenössischen technischen Hochschulen	Swiss Federal Institutes of Technology
EZ	Netherlands	Economische Zaken	Economic Affairs
Fl	Netherlands	gulden	guilder
FNU	Denmark	Det Frie Forskningsråd | Natur og Univers	The Danish Council for Independent Research | Natural Sciences
FOM	Netherlands	Fundamenteel Onderzoek der Materie	(Foundation for) Fundamental Research on Matter - the Netherlands
IT			Information Technology
KNAW	Netherlands	Koninklijke Nederlandse Academie der Wetenschappen	Royal Netherlands Academy of Arts and Sciences

[324] In some cases no English translation could be retrieved because no sources became available.

Abbreviation	Country	Native name or description	English name or description
KTI	Switzerland	Kommission für Technologie und Innovation	Innovation Promotion Agency
KUF	Norway	Kirke-, utdannings- og forskningsdepartementet	Ministry for Education, Research and Church Affairs
M			million
MINAST	Switzerland	Mikro- und Nano-Systemtechnik	Micro and Nano systems technology
NCCR	Switzerland	Nationale Forschungsschwerpunkte	National Centres of Competence in Research
NFP	Switzerland	Nationales Forschungsprogramm	National Research Program
NFR	Norway	Norges Forskningsråd	Research Council of Norway
NOK	Norway	Norske kroner	Norwegian crowns
NSET	United States	Subcommittee on Nanoscale Science, Engineering and Technology	
NTNU	Norway	Norges Teknisk-Naturvitenskapelige Universitet	Norwegian University of Science and Technology
NWO	Netherlands	Nederlandse organisatie voor Wetenschappelijk Onderzoek	The Netherlands Organization for Scientific Research
RFO			Research Funding Organization
SBF	Switzerland	Staatsekretariat für Bildung und Forschung	State Secretariat for Education and Research
SEK	Sweden	svensk krona	Swedish crown

Abbreviation	Country	Native name or description	English name or description
SJVF	Denmark	Statens Jordbrugs- og Veterinærvidenskabelige Forskningsråd	Danish Agricultural and Veterinary Research Council
SNF	Denmark	Statens Naturvidenskabelige Forskningsråd	Danish Natural Science Research Council
SNF	Switzerland	Schweizerischen Nationalfonds (zur Förderung der wissenschaftlichen Forchung)	Swiss National Science Foundation
SNI	Switzerland	Swiss Nanoscience Insitute	Swiss Nanoscience Insitute
SPP	Switzerland	Schwerpunktprogramme	Priority programs
SSF	Sweden	Stiftelsen för Strategisk Forskning	Swedish foundation for Strategic Research
SSVF	Denmark	Statens Sundhedsvidenskabelige Forskningsråd	Danish Medical Research Council
STM			Scanning Tunneling Microscope
STOA	European Union		Science and Technology Options Assessment - European Parliament
STT	Netherlands	Stichting Toekomstbeeld der Techniek	STT has no official English name
STVF	Denmark	Statens Teknisk-Videnskabelige Forskningsråd	
SUK	Switzerland	Schweizerische Universitätskonferenz	Swiss University Conference

Abbreviation	Country	Native name or description	English name or description[325]
TNO	Netherlands		
TOP	Switzerland	Technologie Orientiertes Program	Technology Oriented Program
UMTS			Universal Mobile Telecommunications System

[325] In some cases no English translation could be retrieved because no sources became available.

12 English and Dutch summaries

12.1 Summary

Research councils and other public organizations for research support, RFOs (research funding organizations) for short, have to accommodate to ongoing developments in science and technology. RFOs are designed to do so, but in practice it may be difficult, particularly when new and interdisciplinary fields of research emerge. This leads to the central theme of this thesis: 'How do research funding organizations respond to emerging fields of research and what is the effect of the response on both the new field and the funding organization itself?'

The field of nanosciences & technologies (nanotechnology for short), the case that will be studied in this thesis, is a highly interdisciplinary field, incorporating physics, chemistry, life sciences and engineering. To many RFOs, such interdisciplinarity is problematic because they are organized along disciplinary borders. Secondly, nanotechnology research focuses on phenomena that take place at the nanoscale, which is 10 to 1000 times smaller than the microscale. This requires the use of advanced equipment and/or laboratory space, which may be quite costly and require ongoing investments to maintain and to operate them. To finance them, researchers turn to RFOs when their research institutes' and universities' regular budget cannot support such costs.

A third problem to RFOs, in particular when they attempt to identify and develop strategic priorities, is that it need not be clear what a new field like nanotechnology is about. Actors inside and outside research may have different opinions, and these opinions may change.

In this thesis, nanotechnology serves as the case for a comparative study of RFO behavior in the light of the problems outlined above. Countries studied are Finland, the Netherlands, Norway and Switzerland. RFOs in Denmark, France, Germany, Sweden and the United Kingdom are taken into account as well, but in less detail. As it turned out, the developments in each of the four main countries studied highlight a particular aspect of RFO behavior.

The Swiss National Science Foundation (SNF) showed that the program funding instruments that were in place and being developed were able to pick up on the field of nanotechnology comparatively early and were able to continue funding the field as it developed in Switzerland.

SNF's response is an example of a continued business-as-usual approach, which lived up to needs of researchers and together with other funding initiatives, contributed to a gradual build-up of nanotechnology expertise and research networks. Nanotechnology was developed during a period of increasing demands on RFOs to orient their funding efforts towards economic and other societal relevance. A striking feature of SNF's instruments is that they combine bottom up development of program proposals and scientific quality evaluation by researchers with an explicit role for the federal ministry responsible for research and education to assess societal relevance of program proposals.

As so-called resource dependence theory argues, any organization is highly dependent on resources provided by actors in its environment, which are thus in a position to put demands on the organization. In order to survive, it needs to manage these dependencies, which may include simply living up to demands. RFOs depend on ministries to provide budget, but also on researchers to provide project or program proposals, and peer reviews of these proposals. All this was in place in case of the Swiss SNF. SNF distinguishes itself from RFOs in other countries by living up to the above mentioned demands for societal orientation through the federal Ministry's direct societal quality assessment of program proposals.

Another general issue is the distinction between basic research and technology development. In a number of countries, separate RFOs exist for technology development and for basic research, hereafter referred to as technology RFO and science RFO respectively. The field of nanotechnology offers a challenge because of the overlap between basic science and technology development. The phenomena that occur at the nanoscale are not well understood, which provides ample opportunity for basic research. At the same time, the new functionalities of the phenomena provide a basis for promises of new technological development and societally worthwhile applications.

In Finland, internal as well as external pressures push for the technology RFO, Tekes, and the science RFO, the Academy of Finland, to cooperate. Where nanotechnology is concerned, they did so on two occasions, but the cooperation appeared to not reach a deep level. Whereas the initial program was developed as a common program, on the second occasion, most cooperation occurred after funding programs for nanotechnology were initiated and developed at both RFOs.

This finding can be explained with the help of resource dependence theory. The RFOs' resource dependencies had become stabilized in terms of their own, and very different, internal practices of information aggregation, program development and project proposal review. This made it difficult, if not impossible for the two RFOs to achieve close cooperation.

The Dutch case shows further resource dependency dynamics. The science RFO, the Netherlands Organization for Scientific Research (NWO), was bypassed by a number of cooperating research groups in search of substantial funding for their nanotechnology research plans and accompanying investments in equipment and facilities mobilizing substantial resources from a government investment program in research infrastructure. This resulted in the NanoNed R&D consortium.

The consortium's research program was an alternative funding opportunity to researchers, and a follow-up program was expected. This threatened NWO's intermediary position because researchers turning to this alternative might also move away from NWO. In addition, NWO's priority setting role was at stake as well. Some of NWO's divisions then participated strongly in a research agenda development initiative, and this made them partner in attempts to acquire follow-up funding for the nanotechnology program. The conclusion is that this Dutch RFO showed a strategic response, i.e. to the threat to its intermediary resource position, rather than a prioritizing response of its own to the emerging field of nanotechnology.

The Norwegian developments also showed how Norway's single RFO for science and technology-development funding, the Research Council of Norway (NFR) was bypassed, But here, NFR's central role in research funding was quickly restored after a consortium of researchers had lobbied with the Ministry of Research and Education for a materials research program. Within NFR, the resulting budget for that field became merged with a program for nanotechnology. After that, the nanotechnology/materials research priority, embodied in the NANOMAT program, became part of ongoing policy making processes of the Ministry of Research and Education in which NFR plays an important advisory role. In addition, NFR was in a process of reorganization, which also led to shift in attention within the NANOMAT program from basic materials research to development of nanotechnology. The Norwegian case highlights how policy making processes and NFR's organizational structure and changes therein, constantly shape and reshape the notion of nanotechnology as promoted by NANOMAT. In this ongoing translational process, actors cannot deviate too much from others because that may risk loss of resources. In Norway this is particularly visible because of its comparatively tight resource dependencies between Ministry, NFR and researchers.

The issues highlighted in each of the cases are visible more generally. A science technology divide can be found not only in Finland, but in Switzerland and the Netherlands as well, perhaps even within the Norwegian NFR. Ongoing shaping and reshaping of notions of nanotechnology can be identified not only in the Norwegian chapter, but also in the Dutch, Finnish and Swiss cases.

An important finding spanning the cases is that all RFOs have approached nanotechnology in a conservative way, that is, through the procedures and instruments that were already in place, even if these did not address nanotechnology's interdisciplinary character or researchers' demands for equipment and facilities to do nanotechnology research. Given their resource dependencies, RFOs can hardly do anything else but take a conservative stance. But when their resource supplies are threatened, they tend to adapt in order to secure their resources.

Thus, one can distinguish four stages of upcoming and increasing pressure on an RFO and its responses to nanotechnology: nano is around; a promising new field is recognized; reluctant institutional change; and organizational change to address nanotechnology's challenges.

There is a policy implication. Bowing to increasing pressures to directly address societally relevant research issues may make RFOs vulnerable to hypes, so their conservatism shields them from rash decisions, even if it can also make them too little responsive to the new challenges. If they manage to distinguish between hype and substantial developments, the challenges of newly emerging interdisciplinary fields are an opportunity to do things differently.

12.2 Samenvatting

Research councils en andere publieke organisaties voor financiering van onderzoek, afgekort tot RFO (voor research funding organizations in het Engels), moeten zich aanpassen aan voortdurende ontwikkelingen in wetenschap en technologie. RFOs zijn daarvoor ingericht maar in de praktijk kan het moeilijk zijn, met name wanneer nieuwe interdisciplinaire velden van onderzoek opkomen. Dit leidt naar het centrale thema van dit proefschrift.: 'Hoe reageren RFOs op opkomende velden van onderzoek en wat is het effect van hun reactie op het nieuwe veld en op de RFO zelf?'

Het veld van nanowetenschappen en -technologieën (hierna kortweg nanotechnologie), de casus voor dit proefschrift. Het is een sterk interdisciplinair veld waarin fysica, chemie, levenswetenschappen en -engineering samenkomen. Voor veel RFOs is een dergelijke mate van interdisciplinariteit problematisch omdat ze disciplinair zijn opgedeeld of ingedeeld. Ten tweede, nanotechnologie richt zich op fenomenen die zich afspelen op de schaal van nanometers welke 10 tot 1000 keer kleiner is dan de schaal van micrometers. Hiervoor is geavanceerd instrumentarium en/of laboratoriumruimte nodig die vrij kostbaar kunnen zijn en voortdurende investeringen in onderhoud en gebruik vergen. Als hun onderzoeksinstituut of universiteit die kosten niet uit het reguliere budget kan opbrengen, wenden onderzoekers zich tot RFOs.

Een derde probleem voor RFOs, met name voor RFOs die proberen strategische prioriteiten te identificeren en te ontwikkelen, is dat het onduidelijk kan zijn wat een nieuw veld zoals nanotechnologie precies inhoudt. Actoren, zowel onderzoekers als anderen, kunnen van mening verschillen en hun meningen kunnen veranderen.

In dit proefschrift dient nanotechnologie als casus voor een vergelijkende studie van het gedrag van RFOs in diverse landen in het licht van de hierboven geschetste problemen. De betreffende landen zijn Finland, Nederland, Noorwegen en Zwitserland. Daarnaast zijn ook RFOs in Denemarken, Duitsland, Frankrijk, het Verenigd Koninkrijk en Zweden bestudeerd, zij het minder gedetailleerd. Het bleek dat de ontwikkelingen in elk van de vier landen een bepaald aspect van het gedrag van RFOs naar voren brengen.

De casus van de Schweizerischer Nationalfonds zur Förderung der wissenschaflichen Forschung (SNF) laat zien dat de SNF met de bestaande instrumenten voor programmafinanciering, en degene die werden ontwikkeld, in staat was het nieuwe veld van nanotechnologie in een relatief vroeg stadium op te pikken en de financiering van de verdere ontwikkeling van het veld voort te zetten. Deze reactie van de SNF is een voorbeeld van een voortdurende business-as-usual aanpak die tegemoet kwam aan de behoefte van onderzoekers en die, samen met andere financieringsinitiatieven, bijdroeg aan een stapsgewijze opbouw van expertise en onderzoeksnetwerken op het gebied van nanotechnologie.

Nanotechnologie werd ontwikkeld gedurende een periode waarin in toenemende mate van RFOs werd geëist dat ze hun financieringsactiviteiten op economische en andere maatschappelijke relevantie zouden enten. Een opvallende eigenschap van de financieringsinstrumenten van de SNF is dat daarin bottom-up ontwikkeling van programmavoorstellen en beoordeling van wetenschappelijke kwaliteit door onderzoekers, wordt gecombineerd met een expliciete rol voor het federale ministerie dat verantwoordelijk is voor onderzoek en onderwijs, waarin het ministerie de maatschappelijke relevantie van de voorstellen beoordeelt.

Zogeheten *resource dependence* theorie (theorie van afhankelijkheid van middelen of hulpbronnen) stelt dat elke organisatie sterk afhankelijk is van hulpbronnen die door actoren in de omgeving van de organisatie geleverd worden. Die actoren zijn zodoende in een positie om eisen aan de organisatie te stellen. De organisatie moet deze afhankelijkheden managen om te overleven, waarbij managen ook kan betekenen dat de organisatie aan de eisen tegemoet komt. RFOs zijn afhankelijk van ministeries die hen van budget voorzien, maar ook van onderzoekers die voorstellen voor programma's en projecten leveren en de wetenschappelijke kwaliteitsbeoordeling (peer review) van voorstellen uitvoeren. Dit vond allemaal een plaats in de casus van de Zwitserse SNF. De SNF onderscheid zich van RFOs in andere landen doordat aan de bovengenoemde eis van maatschappelijke relevantie wordt tegemoet gekomen via een directe maatschappelijke kwaliteitsbeoordeling van programmavoorstellen door een ministerie.

Een ander aspect van het gedrag van RFOs betreft het verschil tussen fundamenteel en technologisch onderzoek. In een aantal landen bestaan aparte RFOs voor de twee soorten onderzoek: wetenschaps RFOs en technologie RFOs. Nanotechnologie daagt deze tweedeling uit vanwege de overlap tussen fundamenteel en technologisch onderzoek. De fenomenen die optreden op de nanoschaal zijn onvoldoende begrepen waardoor fundamenteel onderzoek nodig is. Tegelijkertijd vormen de functionele mogelijkheden van de fenomenen een basis voor veelbelovende technologische ontwikkelingen en maatschappelijk interessante toepassingen.

In Finland staan de technologie RFO, Tekes, en de wetenschaps RFO, de Academy of Finland, onder interne en externe druk tot samenwerking. Op het gebied van nanotechnologie deden ze dat bij twee gelegenheden waarbij de samenwerking niet diep bleek te gaan. Terwijl de twee organisaties bij de eerste gelegenheid een gemeenschappelijk programma ontwikkelden, kwam bij de tweede gelegenheid de samenwerking op gang nadat de RFOs elk al een programma voor nanotechnologie hadden geïnitieerd en ontwikkeld.

Deze bevinding kan met behulp van resource dependence theorie worden verklaard. De afhankelijkheden van hulpbronnen van de twee RFOs zijn in de loop der tijd gestabiliseerd geraakt in termen van hun respectievelijke, en totaal verschillende, interne praktijken van informatie aggregatie, programmaontwikkeling en evaluatie van projectaanvragen. Door deze verschillen konden RFOs moeilijk, zoniet onmogelijk, tot een diepgaande samenwerking komen.

De Nederlandse casus laat verdere dynamiek van afhankelijkheden van hulpbronnen zien. De wetenschaps RFO, de Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO) werd gepasseerd door een gezelschap van samenwerkende onderzoeksgroepen die op zoek waren naar aanzienlijke financiering van hun onderzoeksplannen op het gebied van nanotechnologie en de bijbehorende investeringen in instrumenten en laboratoriumfaciliteiten. De onderzoeksgroepen wendden zich hierbij tot een groot financieringsprogramma van de Nederlandse regering voor onderzoeksinfrastructuur. Dit resulteerde in het NanoNed R&D consortium.

Voor onderzoekers vormde het onderzoeksprogramma van dit consortium een alternatieve bron voor financiering van hun onderzoek en een opvolger van het financieringsprogramma werd verwacht. Dit bedreigde NWOs intermediaire positie omdat onderzoekers die van dit alternatief gebruik zouden maken zich mogelijk van NWO af zouden wenden. Daarbij was NWOs prioriteiten stellende rol ook in het geding. Enkele NWO divisies namen daarop het initiatief tot de gezamenlijke ontwikkeling van een onderzoeksagenda voor nanotechnologie waarmee zij zich aansloten bij pogingen follow-up financiering te verwerven voor NanoNed. De conclusie is dat NWO in mindere mate reageerde op de opkomst van het nieuwe onderzoeksgebied van nanotechnologie, maar vooral een strategische reactie gaf op een bedreiging van haar intermediaire positie in afhankelijkheden van hulpbronnen.

De Noorse RFO, de Norges Forskningsråd (NFR), is een RFO voor financiering van zowel wetenschappelijk als technologisch onderzoek. Ook de NFR werd gepasseerd, maar zijn centrale rol in onderzoeksfinanciering werd snel hersteld nadat een consortium van onderzoekers succesvol was in een lobby voor een onderzoeksprogramma op het gebied van materialenonderzoek. Binnen NFR werd het budget dat zodoende voor dat onderzoek beschikbaar kwam samengevoegd met een programma voor nanotechnologie, hetgeen resulteerde in het NANOMAT programma. Daarna werd de prioriteit voor nanotechnologie/materialenonderzoek onderdeel van het normale proces van beleidsontwikkeling bij het Noorse Ministerie voor Onderzoek en Onderwijs, waarbij NFR een belangrijke adviserende rol speelt. Tegelijkertijd werd NFR gereorganiseerd waardoor het zwaartepunt binnen het NANOMAT programma verschoof van fundamenteel materialenonderzoek naar nano-technologisch onderzoek. De Noorse casus brengt naar voren hoe beleidsprocessen, NFRs organisatiestructuur en veranderingen daarin de door NANOMAT gehanteerde betekenis van nanotechnologie veranderen. In dit voortdurende translatieproces kunnen actoren nooit te veel van anderen afwijken zonder het risico van verlies van hulpbronnnen te lopen. Dit is in Noorwegen bijzonder zichtbaar omdat de afhankelijkheden tussen het ministerie, NFR en onderzoekers relatief sterk zijn.

De aspecten die via de verschillende casussen naar voren worden gebracht zijn breder zichtbaar. Een splitsing tussen wetenschaps- en technologiefinanciering is niet alleen in Finland aanwezig, maar ook in Zwitserland en Nederland, en mogelijk zelfs binnen de Noorse NFR. Voortdurende veranderingen in de betekenis van nanotechnologie kunnen behalve in de Noorse casus ook in de Finse, Nederlandse en Zwitserse casussen gevonden worden.

Een belangrijke bevinding die dwars door de casussen gaat, is dat de RFOs conservatief op de opkomst van nanotechnologie hebben gereageerd, dat wil zeggen via reeds bestaande procedures en instrumenten, ook als die geen rekening houden met het interdisciplinaire karakter van nanotechnologie of de benodigde onderzoeksinstrumenten en laboratoriumfaciliteiten. Gegeven hun afhankelijkheden van hulpbronnen kunnen RFOs ook bijna niet anders dan op dergelijke conservatieve wijze reageren. Wanneer deze afhankelijkheden in het geding zijn, zijn ze geneigd zich aan te passen om de beschikbaarheid van hulpbronnen zeker te stellen.

Men kan vier stappen of fasen onderscheiden in opkomende en toenemende druk op een RFO en diens reactie op nanotechnologie: nano komt voor; een nieuw en veelbelovend veld is geïdentificeerd; onbereidwillige institutionele verandering; en organisatie aanpassingen om de uitdagingen van nanotechnologie aan te gaan.

Er is een beleidsimplicatie. Buigen onder de toenemende druk zich direct op maatschappelijk relevante onderzoeksthema's te oriënteren, maakt RFOs kwetsbaar voor hypes. Hun conservatieve houding beschermt hen tegen overhaaste beslissingen, ookal kan dat hen ook te ongevoelig voor nieuwe uitdagingen maken. Als RFOs in staat zijn hypes van substantiële ontwikkelingen te onderscheiden, dan kunnen de uitdagingen van nieuw opkomende interdisciplinaire gebieden een gelegenheid of kans vormen zaken op een nieuwe manier aan te pakken.