Effects of 'Mode 2'-Related Policy on the Research Process:

The Case of Publicly Funded German Nanotechnology

Andreas Wald

Recent reforms in science policy seem to be in line with the archetype of 'Mode 2' of knowledge production. This study on publicly funded German nanotechnology research seeks answers to questions concerning the prevalence, the effects and the appropriateness of Mode 2-related policy. The level of analysis is the individual research group. The results reveal that nanotechnology research does not fit into the picture portrayed by Mode 2 literature. Nevertheless, effects of Mode 2-related policies can be observed. Funding schemes often require an immediate relevance for commercial application and collaboration with industry partners. As a consequence, research groups are forced to adjust their research lines and strategies to these needs. The researchers seriously criticize these developments and consider the policies underlying them as harmful for both fundamental and applied research. In the light of the results, the adaptation of Mode 2 elements into science policy and into funding schemes should be considered critically.

Keywords: science policy, Mode 2, nanotechnology, knowledge production

Work on new modes of knowledge production has been seriously criticized for its limited empirical relevance and conceptual flaws (Weingart, 1997; Godin, 1998; Shinn, 1999; Hellström and Jacob, 2000). Nevertheless 'Mode 2', 'post-normal science' and 'triple helix' have become buzzwords among academics (Funtowicz and Ravetz, 1993; Leydesdorff and Etzkowitz, 2000; Gibbons et al., 1994). Furthermore, claims made by the concepts are mirrored by science policy makers and funding agencies. Recent reforms in the governance of research and the setup of funding programs in many countries comprise elements of the concept of Mode 2. Whether Mode 2 rhetoric influenced policy making or the policy instruments served as a guideline for the formulation of the models remains unclear. However, the promotion of transdisciplinary research, the encouragement of network-building for academic-industry cooperation, and the focus on high profile research with a visible relevance for society are central elements of both, science policies and models of new modes of knowledge production (Weingart, 1997, Hemlin, 2001; Beesley, 2003; Braun, 2005). Although these policy targets and issues have been discussed for many years, they have recently gained more influence (Jacob, 2001; Nowotny, 2005).

These central elements are also applicable to Germany which, compared to other European countries, is a latecomer in reforming its research system. Due to resistance from powerful actors, contradictory demands from different stakeholders and organizational inertia, the reform process took longer to start. Nonetheless, reforms in Germany are driven by the same rationale: the need to foster and safeguard the international competitiveness of the national innovation system, on the one hand, and an increasing scarceness of public resources on the other hand. Like most western countries, publicly funded research increasingly has come under pressure for public legitimization (Dasgupta and David, 1994; Slaughter and Leslie, 1997; Metcalfe, 1997; Hellström and Jacob, 2000; Jacob, 2001; Pavitt, 2001; Martin, 2003; Nowotny, 2005).

The empirical evidence for the developments towards new modes of knowledge production and the observable effects remain ambiguous and the question whether a general orientation of science policy on Mode 2 is a beneficial strategy is still unresolved. While some authors argue that an alignment of science policy instruments on Mode 2 is a necessary precondition for enhancing economic growth and international competitiveness (Beesley, 2003), others consider such strategies as harmful for the long-term prospects of fundamental research as well as corporate R&D (Dasgupta and David, 1994: 513-518; Metcalfe, 1997; Shinn, 1999; Wilts, 2000; Mulvey, 2002; David, 2002).

Against this background, the aim of this paper is to analyze possible effects of Mode 2-related elements of research policy on the research process in publicly funded German nanotechnology. The focus lies on the individual research group which is defined as the smallest stable unit in an organization that conducts research (Wald et al., 2007: 218). The micro-level has been chosen as the level of analysis because universities and extra-university research institutes are professional organizations (Mintzberg, 1979: 355). In this type of organization, the operating core, i.e. the research group or the individual senior researcher, is the power base. The study addresses three questions concerning the effects and the appropriateness of Mode 2-related policies:

- Are there policies in line with Mode 2 and how prevalent are they in publicly funded research?
- Is there empirical evidence for nanotechnology being a typical Mode 2 field?
- What are the consequences of Mode 2-related policies and how are the policies evaluated?

This study empirically analyzes the field of nanotechnology which has been characterized as a prototype for Mode 2. Nanotechnology is a science-based field of technology which bridges various scientific disciplines (Meyer, 2001; Schmidt, 2004). Furthermore, it is considered to be an important future technology since nanoscience research is assumed to result in radical improvements of human life and in high economic pay-offs. Due to its interdisciplinary nature, nanotechnology research often requires the combination of complementary resources from different fields. It is therefore prone to network building and collaboration between science and technology (Bozeman et al., 2007). Finally, nanotechnology is the centerpiece of science policies in many countries. Programs of governments and funding agencies, like the American Nanotechnology Initiative, invest heavily in nanotechnology research and development (NSTC, 2000; Roco and Bainbridge, 2001; Metha, 2002; Glimmel, 2004; Johnson, 2004).

I will begin by first describing the design of the study. In the next section, central characteristics of Mode 2 and related concepts are described. In the third section it is argued, that elements of Mode 2 can be also observed in many science policy instruments. I then continue by introducing nanotechnology and describing the organization of the publicly funded part of the German research system. Moreover, evidence for Mode 2-related policies are provided. This is followed by an empirical examination of whether the research in nanotechnology exhibits elements of a Mode 2 field and how Mode 2-related policies affect research. The evaluation of the policies takes place in the seventh section. In the concluding part, the usefulness of a standardization of science policies based on the archetype of Mode 2 is discussed.

Research design

The population of nanotechnology research groups in Germany has been identified in a two-step procedure (Wald et al., 2007). In a first step, a bibliometric analysis of the Science Citation Index (SCI) revealed all institutions that published at least one article in the field of nanotechnology in 2002 and 2003. Unfortunately, SCI-data does not exist at the level of research groups, but is only available in order to identify the institutional affiliation of individual researchers. The list of institutions, thus, had to be disaggregated using secondary information from directories and web pages. In a second step, this group level listing was validated in expert interviews at the federal funding agency that manages the funding programs relevant for nanotechnology at the Federal Ministry of Education and Research. The expert interviews resulted in a population of 223 research groups. The research group is defined as the smallest stable unit within an organization that conducts research. For identifying research groups a realistic rather than a nominalistic approach was pursued. Consequently, a research group may also correspond to a formal organizational unit, e.g. a subdivision or a chair, but must not.

The study is based on a random sample of 25 research groups. Of the original sample, five groups refused to participate in the study. They were replaced by a random selection of five alternative cases. As the sample only comprises about 10% of the population, the generalization of the results will be limited to some extent. Nevertheless, the main types of institutions working in this field are represented. Furthermore, the different subfields, such as nanoelectronics, nanomaterials and surfaces, and nanobiotechnology are also covered by the sample. This is important since the different subfields have different structures and exhibit different logics of research. In table 1, the composition of the sample is compared to the population. In general, the sample represents the structure of the population quite well.

Table 1: Composition of the sample.

	Sample	Population
University	18 (72%)	143 (64.1%)
Max-Planck-Society (MPG)	2 (8%)	29 (13%)
Leibnitz-Association (WGL	1 (4%)	6 (2.7%)
Helmholtz-Association (HGF)	2 (8%)	16 (7,2%)
Fraunhofer-Association (FhG)	1 (4%)	7 (3.1%)
other	2 (8%)	22 (9.8%)
Total	25*	223

* one group with double affiliation

Universities are slightly overrepresented whereas non-university institutes, especially of the Max-Planck-Society, are slightly underrepresented.

The average size of the research group is 13.8 scientists (full-time equivalents). In universities, the research groups are mostly smaller than in non-university institutes. The data has been collected in face-to-face interviews with the heads of the research groups. All interviews have been recorded and transcribed. The interviews were designed as semi-structured, qualitative, expert interviews complemented by a standardized questionnaire covering data on size, input (personnel), and output (publications, patents) of the group. In addition to the qualitative data, a formalized questionnaire was used to collect data on the ego-centered networks. First, the interviewees were asked to make a list of their most important partners for scientific collaboration. Subsequently, the interviewees had to provide information about their partners. Moreover, they described the relations between themselves and their partners, as well as the relations between their partners.

The qualitative interview data was subjected to a computer based content analysis using the software package ATLAS.ti (Krippendorff, 2003). To avoid a subjective bias, the whole text material was examined separately by three persons. The textual information was categorized. The coding frame relates to the different Mode 2 policy instruments described in the sections 3 and 4. Each person assigned the categories of the coding frame to different parts of the transcripts. In a second step, the results of the three separate analyses were consolidated. For the most part, the results of the three investigators were identical. For discrepant categorizations, an intensive discussion led to a common assignment of textual parts to the categories. This procedure resulted in 25 transcripts indexed by the empirical categories shown in tables 2 and 3. One group of categories deals with the factors that influence decisions on research lines and research programs. The second group comprises descriptions about the factors influencing the choice of research collaborators and factors that influence the establishment and development of research networks.

‘Mode 2’, ‘triple-helix’, and ‘postnormal science’

Several catchwords have been coined to describe fundamental changes taking place in the organization of science.

The most common concepts are the 'postnormal science' (Funtowicz and Ravetz, 1993), 'Mode 2' (Gibbons et al., 1994), and the 'triple-helix' (Etzkowitz and Leydesdorff, 2000). Throughout the literature, an intensive discussion is taking place about the merits and flaws of the concepts. The critique exhibits three major lines of attack. First, the question of novelty has been raised as the concepts are suspected to reheat some of the ideas related to 'finalized science' suggested many years before (Böhme et al., 1973; Schäffer, 1983; Weingart, 1997). Second, the models are formulated in an ambiguous way and are not specified as rigorous and consistent theories. Third, the presumptions are not substantiated by empirical observations. Empirical evidence suggests that Mode 2 is a form of knowledge production for only a limited number of fields of science (Weingart, 1997; Godin, 1998; Shinn, 1999; Hellström and Jacob, 2000; Birrer, 2001).

The aim here is not to recapitulate the critique in detail but to identify and elaborate the central features of the models. One should be aware that the models differ in some aspects (Weingart, 1997; Wilts, 2000). However, the different models can be subsumed under the keyword Mode 2 as the central assumptions and conclusions are similar for the most part. The new models of knowledge production are assumed to exhibit the following characteristics (Weingart, 1997; Godin, 1998; Shinn, 1999; Hellström and Jacob, 2000; Wilts, 2000; Birrer, 2001; Metha, 2002):

1. The choice of research topics is no longer driven by curiosity but determined by its application relevance. Consequently, the focus of research is on problem and context oriented solutions and less on universally valid basic laws.
2. Research is no longer organized along lines of academic discipline, but is instead transdisciplinary in its orientation.[1]
3. The places of inquiry are not limited to universities and academic institutes, but also consulting firms, government agencies, and other non-academic institutions are involved.
4. Institutional and disciplinary boundaries become increasingly blurred and collaborations in informal networks of changing configurations are the prevalent organizational form. The actors in these networks have different disciplinary backgrounds and different institutional affiliations (e.g. universities, industry). Particularly industry-academic collaboration is required for solving practical problems.
5. Disciplinary organized peer-review is not the sole instrument of quality control. Economic and social usefulness serve as additional criteria for assessing the quality of the research output.
6. As economic, political, and societal actors become important stakeholders for scientists, Mode 2 research is socially responsible. The societal and political implications of the research outcomes have to be taken into account by the researchers.

All in all, Mode 2 differs significantly from the linear model of innovation where fundamental research, applied research, and industrial development are clearly separated by distinguishable cultural boundaries. Mode 2 literature describes the innovation process as collaboration in transient and heterogeneous research teams and networks (Wilts, 2000; Jansen, 2007).

Science policy

Apart from the discussion of whether Mode 2 is in fact a new form of knowledge production and whether it is superseding the traditional Mode 1, several elements of the model seem to be part of the policies of governments and funding agencies (Pavitt, 2001, Beesley, 2003; Glimmel, 2004; Johnson, 2004; Braun, 2005). It is, however, questionable whether Mode 2 rhetoric has influenced science policy or whether the new policy instruments were the trigger for the development of the concepts. However, a certain congruence of Mode 2 and science policy is obvious.

As a general trend, a convergence of different national and regional innovation policies can be observed (Kuhlmann, 2001). Nevertheless, Anglo-American countries leaped ahead by transforming their research system towards more market and profit-orientation encouraging close collaboration with industry. As shown by Slaughter and Leslie (1997) in their analysis of public research universities in Canada, the United States, the United Kingdom, and Australia, large-scale changes took place in the period between 1970 and 1990. In contrast to the vagueness of the work on new modes of knowledge production, their analysis is based on more convincing data and faculty interviews. Evidence is provided, showing that 'Academic Capitalism' has emerged as the prevalent governance model for higher education and research. This regime is characterized by increased attention to market potential as impetus for research and teaching. As a consequence curiosity-driven research is sacrificed for the sake of applied research. The marketability becomes the main criteria for research grants and decision making within university bodies and is guided by the quest for economic efficiency. The implementation of those decisions is facilitated by the replacement of academic governance and the adoption of professional management structures. New management structures also developed business-like organizational units, e.g. marketing, public relations, and fundraising, and established incentive schemes which favor profitable research. However, the study of Slaughter and Leslie also suggests that academic capitalism does not necessarily represent a threat to basic research, but may also create new opportunities for research.

Quite a few countries on mainland Europe have also adopted science policies that fit the Mode 2 model. Benner and Sandström (2000) report such tendencies for Sweden in their study on the funding of technical research. Early adopters of more market-based governance forms were the Netherlands, where policy instruments like performance-based funding have been introduced in the mid-1980s. State regulation has been reduced while at the same time competition between universities, managerial self-governance and academic self-governance has been strenghtened. More recently, Austria has moved from the state model of university governance to the managerial model (de Boer et al., 2007).

The prime reasons for the advent of academic capitalism are on the one hand the growing costs of research and development and on the other hand increasing constraints of public expenditures (Martin, 2003). Science policy, as every distributive policy, is primarily concerned with the allocation of resources. As public funds are particularly scarce, it seems to be of crucial importance to invest in areas and types of research with high scientific and/or economic returns (Johnston, 1990; Braun, 1998).

A central policy instrument for encouraging applied research with marketable results is priority setting as well as goal setting. Both instruments can be applied externally by government agencies or non-governmental funding bodies as well as internally in universities or extra-university research institutes. Typical for external priority setting is a selective funding of certain research fields. Internal priority setting often appears in the form of profile building in research organizations. Whereas priority setting influences the choice of the research topics, goal setting defines the objectives of the output (Wald et al., 2007).

The promotion of interdisciplinary research and science-industry collaboration is a second fundamental aim of Mode 2-related policy instruments. Bridging the divide between different disciplines and fostering joint research activities of academic and corporate actors can also be achieved by regulating the flow of financial resources. Funding schemes for large and particularly expensive research projects often require the collaboration of several research groups as well as interdisciplinary teams and the cooperation of academic and corporate researchers. Several funding programs at the national and European level, i.e. the European Union funded 'Networks of Excellence', are especially designed to support collaboration across national and institutional boundaries (Wald et al., 2007).

Publicly funded nanotechnology research in Germany

The fundamental scientific advances in nanoscience and its practical implementations by nanotechnology are assumed to result in a revolution of science and technology.[2] Technological breakthroughs in fields like manufacturing, medicine, materials, nanoelectronics, healthcare, agriculture, and information technology are expected to bring about solutions of high social and economical utility. As the variety of applications suggest, nanoscientists have different disciplinary backgrounds. Prevalent fields are physics, chemistry, biomedicine, material science, and electrical engineering (Meyer and Persson, 1998; Schummer, 2004a; 2004b). Nanotechnology is an umbrella term for a large set of technologies working at the molecular level. It is about the ability to manipulate, control, and create matter and structure at the level of 10^{-9} to 10^{-7}meters. One nanometer (nm) is approximately 80,000 times smaller as a human hair (Metha, 2002: 269). The specific characteristic of nanotechnology is that it implies not only a quantitative miniaturization, but the creation of new qualities of materials and devices. Manipulations on the nanoscale result in novel properties of materials at the macro scale (NSTC, 2000; Roco and Bainbridge, 2001; Metha, 2002; Glimmel, 2004). Examples for a potential application of nanomaterials are wear-resistant polymers for tires, or nanomachines that can be used for medical treatment, e.g. in-vivo diagnostics and treatment devices.

The potentials of nanoscience-based innovations are far from being fully exploited. Given the high potential on the one hand and the infancy concerning the state of commercializeable applications on the other hand, national science policies often comprise specific programs for the advancement of the field. Many even consider nanotechnology as the 21st century key technology for enhancing and safeguarding international competitiveness.

Nanoscience in the publicly funded German research system

In the publicly funded sector of the German research system, research is conducted by universities and by extra-university institutes. While research in universities covers both fundamental and applied research within one institution, in extra-university research a clear-cut division of labor between different types of institutions can be observed. The German research system is segmented and highly specialized. Between the different organizations, only a limited overlap concerning the fields and the orientation of research exists (Hohn and Schimank, 1990; Heinze and Kuhlmann, 2007).

Universities pursue fundamental and applied research and are institutionally financed by the federal states. The extra-university sector differs in its research missions and funding base. This sector is composed of the Max-Planck-Society (MPG), the Leibniz-Association (WGL), the Helmholtz-Association (HGF), and the Fraunhofer-Association (FhG). In addition, a few federal institutes provide technical and scientific services. They are directly funded by and report to a federal ministry. Extra-university institutes are particularly competitive actors in the field of nanoscience. The institutes of MPG are responsible for fundamental research. They are funded by the federal government (50%) and the federal states (50%) in which the institutes are located. The high degree of institutional funding is combined with a high autonomy of the institutes regarding their research strategies and the intraorganizational distribution of resources. The funding share of the federal level and the state level is 90:10 for institutes of the Helmholtz Association to which 15 big research centers belong. The centers pursue fundamental and applied long-term research on behalf of the state and society. Research at the HGF is program-based and organized in six major research fields. Many of the research activities require large scale research facilities ('big science') and concern technologies of high complexity. The Leibniz-Association is an umbrella organization which encompasses research institutes being very heterogeneous in size, orientation, and organizational structure (Hohn and Schimank, 1990a: 141-142). The most common funding scheme for most of the institutes is 50% by the federal government and 50% by the federal states. The institutes of FhG constitute the fourth segment of the extra-university sector. Their mission is applied contract research for industrial and public customers. Roughly two thirds of the institute's revenues come from contract research whereas the remaining third is funded by the federal Government and the federal states. The institutes of the FhG act as profit centers and have a high operational autonomy.

The segmentation of the research system has been criticized within the scope of the ongoing reform process of the German research system. The need for inter-institutional collaboration has been emphasized by political actors and academics, but due to the functional monopolies of the MPG, the HGF, the WGL, and the FhG neither competition nor cooperation between the different institutional pillars took place (Meyer-Krahmer and Schmoch, 1998; Heinze and Kuhlmann, 2007). In this respect, the institutional structure does not facilitate Mode 2 knowledge production where fundamental research should go hand in hand with applied research and industry participation is essential. For instance, institutes of the Max-Planck-Society are not particularly interested in the further development of the original findings as there are no incentives to follow up the matter. Policy makers therefore demand for a closer cooperation between the different institutions (BMBF, 2002). As a first reaction to this claim the Max-Planck-Society and Fraunhofer-Association recently started a dialogue on pooling expertise and know how (Heinze and Kuhlmann, 2007: 205).

The publication activity in nanotechnology (1996-2000 Science Citation Index) shows that the main research stimuli come from the extra-university sector. The 15 most active research facilities comprise seven institutes of the MPG, five university research institutes, and three institutes separated between the HGF and the WGL. An important factor for explaining the high performance of the extra-university sector is the comprehensive institutional funding base. Whereas for universities third party funds are essential, institutes from the MPG, HFG, and WGL have a wider scope for investments in staff, laboratory, and equipment. But also the extra-university sector faces increasing pressure. More strategic industry collaboration, specialization, concentration on core competencies, profile-building, and a higher degree of applied research are fundamental guidelines of the reform process in the German research system which fit well with the rhetoric of Mode 2 (Wissenschaftsrat, 2000; 2002; 2003; Internationale Kommission, 1999).

Elements of Mode 2 policy in publicly funded German nanoscience

German nanoscience ranks high in international comparisons for both fundamental, as well as applied research (Hullmann and Meyer, 2003). It is number one in Europe in terms of publication output and patent applications. Around 600 companies are currently involved in the nanotechnology business, most of them being small and medium sized enterprises. Roughly 50% of all European nanotechnology-firms are headquartered in Germany. The public funding for nano-research amounts to 290 million Euro per year. Compared to other European countries, this is by far the highest budget for publicly funded research in this field (BMBF, 2006).

The funding base for nanoscience is diverse. Universities strengthen their profile by selectively financing highly visible research areas. Nanotechnology is one of the most prominent fields for which these financial incentives are provided. On the federal state-level, so called 'research co-operations', which are collaborations comprising groups from several institutions (public and private), receive funding for dealing with pre-specified topics including nanotechnology. Research cooperations foster interdisciplinary and applied research with industry partners. Those public-private collaborations are expected to boost the transfer from academic research to successful commercialization (Hoppe and Pfähler, 2001; BMBF andd BMWA, 2003).

Likewise, the Federal Ministry of Education and Research (BMBF) considers active collaboration between industry and science as a key factor for successful innovation (BMBF, 2002a: 33; BMBF and BMWA, 2002: 36). Funding nanotechnology since the early 1990s, BMBF primarily supports projects that involve a strong participation of small and medium-sized companies (BMBF, 2004: 25). The underlying assumption is that a funding policy with a strategic focus on selected fields is more likely to foster the development of the national economy.

Within the scope of the increasing Europeanization of national R&D policies, BMBF supported national participants in the 6th EU-Framework-Program. Similar to the national level, EU-related activities of the BMBF are aligned with strategic national goals. The creation of 'Networks of Excellence', an integral part of the 6th-EU-Framework Programme, enforced the establishment of national competence centers. The BMBF expected these centers to profit from the process of Europeanization by solving critical mass problems through strategic national and international networking (BMBF, 2002b). Networks of Excellence (NoE) encourage collaboration between centers of excellence in universities, extra-university research institutes, enterprises, including SMEs, and other science and technology organizations. The activities have a long term horizon and multidisciplinary objectives (European Union, 2002). Besides the NoEs, the integrated projects gained increasing importance for the policy agenda on the national level. Integrated projects were designed in order to "give increased impetus to the Community's competitiveness or to address major societal needs by mobilizing a critical mass of research and technological development of resources and competences" (European Union, 2002).

At the national level, the German Research Foundation (DFG) is the most important funding agency. At first glance, the funding schemes of this source seem to be less influenced by Mode 2-related policies. The DFG offers a variety of programs of which researchers can choose the scheme that fits best to their endeavors. DFG funding is geared towards the requirements of universities (DFG, 2003). Extra-university institutes have fewer prospects to gain funding because of their high institutional funding. Only in special cases, like 'Collaborative Research Centers' or 'Research Groups', can extra-university institutes apply for funding. The DFG does not fund projects with industrial participation but rather fundamental research. One of the most important instruments is the funding within the frame of the 'Individual Grants Programs'. This funding scheme is favored by many researchers as there is no priority setting and there are few administrative guidelines (DFG, 2002: 69).

With DFG funding, however, Mode 2-related elements can also be observed. 'Coordinated Programs' (Priority Programs, Collaborative Research Centers, DFG Research Centers, Graduate Schools) have begun to gain importance. The Collaborative Research Centers and the DFG Research Centers aim to foster scientific excellence, interdisciplinary cooperation, the development of future themes, and profile building in universities (DFG, 2002: 75f.). For instance, 64.6% of the total budget for Collaborative Research Centers in 2004 was spent on life sciences and natural sciences (DFG, 2004: 104), including research fields with a visible relevance for society (medicine, biology, chemistry, etc.).

In short, the funding schemes of the BMBF and the EU often require the participation of industrial partners, the participation of specific European countries, and a focus on applied research and on certain fields of strategic relevance. These regulations are obviously elements of Mode 2 policy. To a lesser extent, also for the DFG-funding a trend towards Mode 2 elements can be observed.

Publicly funded German nanotechnology as a Mode 2 field?

As the foregoing discussion revealed, policies of the federal government and funding agencies exhibit elements of Mode 2. Whether these instruments actually influence the research process of the individual research groups will be analyzed empirically.

Applied vs. fundamental research

A central element of the new mode of knowledge production is its applied orientation. However, for most research groups in publicly funded nanotechnology the orientation of research is fundamental. Only two respondents have a share of applied research which is above 50% (all statements have been translated from German, the institutional affiliation of the group is put in brackets):

> Our main activity is basic research. But we are constantly trying to build a bridge to applied research. (University)

> The mission of our institute is applied research. Through our intense press and public relations activities, it sometimes happens that industry asks us to solve some problems on their behalf […] that's the way how industry projects get started. […] Those projects are nevertheless the result of our prior basic research activities. (Fraunhofer-Association)

For 14 out of 25 interview partners, fundamental research is the core of their activities and represents more than 60% of their overall activities.

> Nanotechnology is almost exclusively basic research. We are dealing with phenomena without having any idea of whether they will be of some future technological use. (Helmholtz-Association)

A third category is (experimental) development which can provide services for both, fundamental and/or applied research. For the scientists in the sample, this activity does not play a prevalent role. Only two respondents dedicate more than 50% of their research to experimental development.

These results do not support the conjecture that nanotechnology research is mainly driven by problem-solving and the development of marketable solutions. In contrast, the majority of the interviewees stated that their research is first of all curiosity driven. They chose their topics depending on individual interests.

> How do our projects emerge? Well, I am personally interested in that field. That started with my diploma-thesis, went on with my PhD-thesis, and now that is the main subject of my research group. (University)

> That is an evolutionary process. Innovative research very often is dependent on chance […]. I can't tell you today of what exactly my research in five years will be about. (Max-Planck Society)

Influence on the choice of research topics

A quite similar picture reveals the statements about the factors influencing the choice of research topics. The genuine interest and path dependency were the most prevalent causes for the selection of topics.

> New questions arise out of our day-to-day business. People observe a new effect which they do not understand […] one starts to analyze the new phenomenon and that is how we develop new ideas. (Helmholtz-Association)

> You have your own specialized field where you are continually working on […]. New ideas generally originate from previous work. (Leibnitz-Association)

In accordance with Mode 2 literature, application relevance also plays an important role for the choice of research topics. This factor influences 10 of the researchers in their decisions about new research projects and topics.

Further important factors for the choice of research topics are internal incentives set by the organization as well as external incentives set by external stakeholders. Internal incentives, such as priority setting and profile building, affect 6 interviewees. External incentives are even stronger and exert influence on 9 research groups. Priority setting also has an impact via the funding schemes of funding agencies. In particular, the policies of the EU and the BMBF require the adjustment of research topics. Researchers have to accommodate their topics, methods, and aims accordingly. As research in nanotechnology is expensive, especially university groups heavily depend on external funding. In the sample, the mean share of third-party funded research on total research is 70.7%, of which 58.3% are provided by foundations and 26.7% by government agencies. Only 8.7% of external funds come from industry.

> We're under constant pressure to apply for grants and to concentrate on those fields with a high probability of getting funded. (University)

The dependency on external funding makes research groups vulnerable to the influence of external stakeholders (Wilts, 2000). The authority over the allocation of scarce financial resources enables funding agencies to influence the cognitive development of science (Braun, 1998). Considering internal incentives and external incentives as Mode 2 policy instruments, it seems safe to conclude that Mode 2 policy influences the research process as far as the choice and the alignment of research topics is concerned.

Transdisciplinarity

Transdisciplinarity and heterogeneous collaboration in academic-industry networks have been identified as central characteristics of a Mode 2 field. In fact, the research groups in the sample are rather homogeneous in their composition. The average number of disciplines in a group is only 2.1. This finding is consistent with other studies in the field of nanotechnology. Although the thematic and applications of nanotechnology cut across disciplinary boundaries,

Table 2: Influence on research topics.

factors influencing the choice of research topics	responses
genuine interests/path dependency	13
relevance in the scientific community	1
internal incentives	6
external incentives	9
application relevance	10
other reasons	7
total	46

n=25, multiple responses

the organization of research at the level of departments and research groups is according to traditional scientific disciplines (Schummer, 2004a).

Influence on network building
Studies on nanotechnology accentuated the outstanding meaning of research collaborations (Heinze and Kuhlmann, 2007). The empirical data substantiates this finding. Collaborations are essential for 22 out of 25 research groups.

> Cooperations are extremely important for our research. Without our partners we would not be able to compete on the international level. (University)

> Cooperations are a necessary precondition for our work. None of our projects could be successfully carried out without our partners. (Fraunhofer-Association)

The main function of the networks is access to complementary resources such as know-how, financial resources, or equipment.

> We predominately combine complementary resources. In our large projects, we cooperate with partners from the fields of information technology and chemistry. (University)

> We always work in a network of partners which provide complementary resources to our own. (Federal state institute)

An important characteristic of new modes of knowledge production is the close collaboration between academic research and industry which is supposed to be due to the fusion between fundamental and applied research. Consequently, a multitude of corporations is expected to be among the network partners of the research groups. However, collaborations in publicly funded German nanotechnology are predominantly academic-academic relationships. Only 11 out of 25 groups cooperate with industry partners. Three of these groups maintain relationships with more than four corporations.

Most groups stressed the importance of collaborations, but described different mechanisms of network building. The choice of partners and the changes in the network structures are dependent on the factors shown in table 3.

An important cause for the formation of networks is path dependency. Scientists meet at conferences or other scientific meetings and converse. In case of common interests and mutual appreciation joint projects emerge. Path dependency as a factor influencing network building has been reported by 18 research groups.

> Most of the collaborations are on the basis of personal relationships. We cooperate with people not with institutions. (University)

The most prevalent factor is the strategic choice of partners. For conducting ambitious research projects, complementary skills, know-how, or other resources are necessary. Researchers actively seek for partners with the relevant skills in the whole scientific community (open search). Twenty groups pursue this strategy when looking for collaborations. Another strategy is the search in a limited pool of previous partners which 7 groups pursue.

> The main thing is to identify and to select partners, who have particular knowledge and skills. […] somewhere

Table 2: Influence on network building.

factors influencing network building	responses
emergence/path dependency	18
strategic based on a limited pool of partners	7
strategic based on an open search for partners	20
external incentives	5
internal incentices	1
other reasons	2
total	53

n=25, multiple responses

> over the world you will find someone who […] probably has complementary resources to your own, that is how we come together (University)

As for the choice of research topics, internal and external incentives influence network building. Again, external incentives by funding agencies are more common than internal incentives within organizations. External incentives have an impact on the choice of partners for 5 groups whereas internal incentives have only been reported by a single group. The policies of national and supranational funding agencies not only affect the choice of research topics by priority setting and selective funding but also network building as well. As explicated above, the funding schemes often encourage academic-industry collaborations or even presuppose that research is conducted in close cooperation with corporations.

> Besides the dependency on industry resources, the asymmetry is aggravated by public funding schemes which often require the participation of firms and/or the participation of certain countries. (University)

In this section, the focus was on two questions. First, the aim was to find out whether publicly funded German nanotechnology can be considered as a typical Mode 2 field of knowledge production. The answer is: not really. Though some Mode 2 characteristics are observable, academic-industry collaboration, application relevance, and interdisciplinary research are not prevalent in the field. In contrast, Mode 1 elements are much stronger. Disciplinary organization, fundamental research, and curiosity driven choice of research areas and topics dominate the field. The second aim was to analyze whether the research process of nanotechnology research groups is influenced by Mode 2 policy instruments. Here the answer is yes. Priority setting and selective funding of research projects which fulfill certain requirements have an impact on the research process. The choice of research topics and network formation are influenced by Mode 2 policies.

Evaluation of Mode 2 policies

The nanoscientists evaluated the Mode 2 elements of funding schemes on the national and European level. Most of the statements about the effects of the policies are quite negative. All of the 11 research groups engaged in industry collaboration reported negative experiences. From their point of view, funding is slanted towards applied research and industry collaborations. Many scientists characterized their research as predominantly fundamental in its orientation. They consider fundamental research as a necessary basis for any technological application. External pressures for applied research with industry partners prevent them from following their actual duties. In this section, the rationales for the adverse effects of Mode 2 policies will be presented.

First, there is an asymmetric distribution of power between corporate and academic partners. Industry disposes of substantial financial resources and hardly depends on collaborations with universities or extra-university institutes. Publicly funded research, especially in universities, badly needs the resources of corporations. As several interviewees explained, corporate partners are difficult to approach.

> Our main problem is to find clients who need our services regularly. We had [name of a company] but they closed down. That was our best client. With their money, we were able to fund a lot of our activities. Now we need to search for new companies and that is very difficult because some firms hesitate to cooperate. (University)

> A real problem is the cooperation with industry. In all projects, except DFG, the participation of industry is required in the sense that industry provides a lot of money. But the situation of the industry is not very good, so this is a real bottleneck. […] (University)

Second, the asymmetric power relationship provides incentives for firms to exploit their academic partners. A recurrent complaint is that university research groups are considered as a cheap substitute for industrial laboratories:

> The danger of getting ripped off by the industry is always a problem, because they use research groups as cheap labor force […], university research groups that want funding have to cooperate with an industrial partner whether it fits or not. (University)

> […] It started when the industry obviously drew the conclusion that they don't need their own basic research units, because the under-equipped universities will always agree to do research on their behalf, because the universities need the money. (University)

> They expect that we have to develop everything until it can be applied to a technology. But then, only the licensing would be left for the industry. That is not what universities are for. It is not my task to close as much licenses agreements with corporations as possible. (University)

A third problem are the different aims and expectations of academic and private researchers. Industry seems only to be interested in collaboration if universities deliver solutions ready for commercialization. University and extra-university institutes often pursue research projects with a high degree of uncertainty. These different logics of research seem to prevent a closer collaboration.

> […] I want to cooperate with industry as early as possible but in many areas it won't work. When it's more basic

> oriented research and the direct technological application cannot be specified or is quite far away then firms may be interested but they won't give you any money for your research. (Helmholtz-Association)

> We try to identify strategic research fields and just start our research. When we have the first results we try to acquire industrial partners and ask whether they are interested or not. But this approach got more and more ineffective in the last years. […] That means the overlap between the interests of the industry and the universities is getting smaller. (University)

The different aims concerning the outcome are related to dissimilar time scales. Whereas industry has a short-term horizon, university research for the most part is an open search with no finite timeframe. Moreover, the reward systems of business and science are considered to be incommensurate. For researchers pursuing an academic career, publications in scientific journals are essential. Here the priority of scientific discoveries is of utmost importance. In contrast, firms have a strong interest not to disclose their findings in order to realize advantages on the market.

> Industry has no interest to invest. For 10 years, industry is solely interested in a short-term improvement of products. That means that they will give you only their money when you can deliver something just to improve already existing products because they lack the manpower or laboratory to do that on their own. They are not interested in funding basic research nor applied research that goes beyond a two year horizon. (University)

> I don't do mission oriented research. That is something that you can not pursue at a university. If you practice mission oriented research you are selling your soul. Publishing is typically not allowed and the one thing that drives young researchers forward are good publications, they need them for their career and that's the reason why mission oriented research is a taboo. (University)

As many corporations have abandoned any activities of fundamental research, communication with academic partners is becoming increasingly difficult:

> At the moment we've also got the problem that the scientific competence in the industry has strongly decreased. We have difficulties to understand each other. They often don't know what we are talking about. (University)

Finally, researchers from extra-university institutes which dispose of comprehensive institutional funding explained that their mission and self-image prevents them from doing applied research and development for industry. The following statement of a Max Planck scholar emphasizes the identification with the traditional mission of the institute:

> […] we are a basic oriented research institute. That is why we try to export as much as we can. As soon as it goes to an application, we try to give it to other people because this is not our business. […] I mentioned it just before: Application development is not our business. That means it is my job to care that the application is realized outside the institute. It sounds curious but it happens that we get a third party funded project and then I think

> by myself this project is better done by the scientist from the Fraunhofer-Institute. And so I give them these projects including the future benefits that may occur. (Max-Planck-Society)

In short, the pressure for conducting applied research and for seeking collaborations with industry partners is considered difficult, although contacts to industry are generally considered important. The different aims and logics of scientific research and industry research, as well as an asymmetric distribution of power are the main reasons. The scarceness of public funding makes scientists vulnerable to the influence of such policies.

Discussion and conclusion

The results reveal a coherent pattern. The publicly funded nanotechnology research in Germany does not fit to the picture portrayed by Mode 2 literature. Most research groups focus on fundamental research. The division between basic and applied research is still prevailing in the nanotechnology field. The underlying rationale for collaboration is access to complementary resources and the majority of collaborations take place with academic partners. Moreover, transdisciplinarity is not a widespread occurrence.

Nevertheless, the interviewees stated a variety of Mode 2-related policy effects. Funding schemes of public funding agencies, state funding, and EU-programs often require an immediate relevance of the research outcome for industrial application. Collaborations with industry partners are even a prerequisite for earning public funds. In this regard, Mode 2 is different from the earlier debate on the finalization of science (Böhme et al., 1973; Schäffer, 1983). While the latter had been criticized for threatening academic freedom, Mode 2-related policies appear as legitimate and are embraced by policy makers and funding agencies alike (Weingart, 1997). As a consequence, academic research groups are forced to adjust their research proposals accordingly. Research areas with non-existing short-term connection to industrial production are harder to pursue. This finding matches with earlier studies on the impact of university-industry collaboration on academic freedom (Gluck et al., 1987; Blumenthal et al., 1996; 1997) which also showed negative impacts of cooperative research with industry participation. These studies have been conducted in the US and examine clinical and non-clinical life science faculty, a discipline which might be considered as another Mode 2 field. A recent study of Behrens and Gray (2001) came to different results. In their analysis of two engineering departments, no negative influence of industry sponsors on (perceived) academic freedom could be found. As their study was conducted on the level of graduate students, a direct comparison with our results is problematic. It can be assumed that the influence of industry on the choice of the research topic and the research topology is exerted mostly on the principal investigator and not on the level of graduate students. Therefore, the research group might be the more appropriate level of analysis.

Most of the researchers seriously criticized the recent developments. Reforms in the governance of the research system are driven by the need to be seen doing something rather than by the need to get it right. The focus on applied research bears the risk of a decline in the excellence of fundamental research. It leads to an underinvestment of public funds in scientific research which has not or is not assumed to have an immediate practical relevance. The logic of corporate R&D on the other hand does not allow for substituting the lack of fundamental research (Rosenberg, 1990). Market pressure forces private firms to concentrate on marketable developments. The arguments for industry not sufficiently investing in fundamental research are well known and date back to the work of Nelson (1959) and Arrow (1962). It lies in the public good character of scientific knowledge, i.e. the non-excludability and the high degree of uncertainty about the returns (Dasgupta and David, 1994; Metcalfe, 1997). A concentration of funds on applied research and development may enhance short-term and medium-term economic success. But in the long run, fundamental research should not be neglected as there is empirical evidence of increasing interaction between pure science and technology particularly in fields such as nanoscience (Grupp and Schmoch, 1992; Narin et al., 1995; 1997; Meyer, 2000). That means that the new knowledge created by fundamental research may be useful for applied research and product development and vice versa. However, the coherence between basic research and economic payoff is very complex and not as simple as suggested in the linear model of innovation (de Solla Price, 1984; Rip, 1992; David et al., 1994: 74). There is even some evidence that most innovations are not based on pure academic research but are developed within corporate R&D activities (Kealey, 1996: 216-219; 1998). In contrast, David et al. (1994) argue that the economic payoffs from basic research are not easy to assess as not only direct costs and benefits have to be taken into account, but also terms of learning and information. Economic returns of fundamental research often occur in the form of externalities. That argument has also been accentuated by Pavitt (2001). Fundamental research develops trained researchers who will be of use for industrial research at a later time.

Several interviewees characterized the funding policy of state programs as hidden industry subsidization rather than research funding. Subsidizing industry R&D by publicly funded research may also lead to an underinvestment in applied research by private firms. This in turn will reduce the performance of corporate R&D. Industry is taking advantage of a situation characterized by the scarceness of public funds. Universities especially are facing cuts in their institutional funding and researchers are increasingly dependent on external funding. Corporate actors often consider their academic partners as cheap product development units.

As we deal with a small sample, the results should be treated with some caution. The sample, however, encompasses research groups from all pillars of the German research system and therefore represents the structure of the population well. Probably a more serious problem is the limited generalizability beyond the national research system. One should be aware that the study is focused on the German research system. The structure of this system has been characterized as highly segmented. As this segmentation is not supportive to Mode 2, the results may to some extent be caused by that particular institutional structure. In other institutional settings, other effects of Mode 2-related policies may be observed. Nevertheless, German nanotechnology research is among the top five in the world, and there are no other studies which have analyzed the effects of Mode 2-related policies on the level of research groups. Thus, the study can be considered as a first step for more encompassing comparative research.

Another point that could be raised against the research design is the way data is collected. As the principle of academic freedom is deeply rooted in the scientists' minds and also guaranteed by the constitution, there might be a general distrust against any form of external influence from policy makers or funding agencies. Consequently, some of the statements might be exaggerated. In a situation of researchers interviewing researchers, a tendency to blame external circumstances for any grievances may come up. Nonetheless, the qualitative approach with extensive interviews seems to be appropriate for gaining in-depth insight into the logic of knowledge production in the field.

Despite the limitations of the research design, the overall picture is consistent and there is evidence for the main argument. In the light of the empirical results, the adaptation of Mode 2 elements into national science policy and into the requirements for eligibility for research grants should be considered critically. The simple logic that a concentration of public funds on industry related research enhances innovation and economic growth does not apply. Even in a field generally considered as typical for Mode 2, policy effects are evaluated as harmful for the excellence of both fundamental as well as applied research. Consequently, Mode 2 should not be recommended as a general frame for science policy.

Acknowledgements

This paper presents results of a project funded by the German Research Foundation (DFG) - JA 548/5-1.

I am deeply indebted to Karola Franke for the excellent co-operation throughout the whole project.

I would like to thank all those we have interviewed for their expertise and time.

I also wish to thank Dorothea Jansen, who as the principal investigator provided her valuable support and advice.

I am grateful to Jochen Gläser and Arie Rip for critical comments on earlier versions of the paper.

Notes

1 The terms 'interdisciplinary', 'transdisciplinary', 'multidisciplinary', or even 'superinterdisciplinary' are used with partially different meanings (Schummer, 2004a; 2004b). In this article, the terms are used as synonyms and define interdisciplinary as joint research work of scientists of at least two different disciplinary backgrounds.

2 For simplicity, nanoscience and nanotechnology are used synonymously.

References

Arrow, K.
1962 "Economic welfare and the allocation of resources for invention." Pp. 609-625 in Nelson, R. R. (Ed.), The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton: Princeton University Press.

Beesley, L. G. A.
2003 "Science policy in changing times: Are governments poised to take full advantage of an institution in transition?" Research Policy 32: 1519-1531.

Behrens, T. B. & Gray, D. O.
2001 "Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome." Research Policy 30: 179-199.

Benner, M. & Sandström, U.
2000 "Institutionalizing the triple helix: research funding and norms in the academic system." Research Policy 29: 291-301.

Birrer, F.
2001 "Combination, hybridisation and fusion of knowledge modes." Pp. 57-68 in Bender, G. (Ed.), Neue Formen der Wissenserzeugung (New forms of knowledge production). Frankfurt: Campus.

BMBF
2002a "Bundesministerium für Bildung und Forschung: Förderprogramm IT-Forschung" (Federal Ministry of Education and Research: Funding program for IT-research 2006).
2002b "Bundesministerium für Bildung und Forschung: Strategische Neuausrichtung – Nanotechnologie in Deutschland" (Federal Ministry of Education and Research: Strategic reorientation – nanotechnology in Germany). "Handlungsrahmen für eine Strategieentwicklung in der Nanotechnologie" (Framework of action for strategy development in the area of nanotechnology).
2004 "Bundesministerium für Bildung und Forschung: Nanotechnologie erobert Märkte" (Federal Ministry of Education and Research: Nanotechnology conquers the markets). "Deutsche Zukunftsinitiative für Nanotechnologie" (German initiative for the future of nanotechnology).
2006 "Förderkonzept Nanoeletroik" (Funding concept in nanoelectronics).

BMBF and BMWA
2002 "Innovation Policy. More Dynamic for Competitive Jobs." Bonn.

BMBF and BMWA
2003 "Zukunft gestalten. Innovationsförderung" (Shaping the future. Promoting innovation). "Hilfen für Forschung und Entwicklung" (Supporting research and development). Bonn/Berlin.

Böhme, G., van den Daele, W. & Krohn, W.
1973 "Die Finalisierung der Wissenschaft" (The finalization of science). Zeitschrift für Soziologie (Journal of sociology) 2, 2: 128-144.

Bozeman, B., Laredo, P. & Mangematin, V.
2007 "Understanding the emergence and deployment of 'nano' S&T." Research Policy 36: 807-812.

Blumenthal, D., Campell, E., Causino, N. & Seashore-Louis, K.
1996 "Participation of life-science faculty in research relationships with industry." New England Journal of Medicine 355, 23: 1734-1739.

Blumenthal, D., Campell, E., Anderson, M., Causino, N. & Seashore-Louis, K.
1997 "Withholding the results in academic life science: evidence from a national survey of faculty." Journal of the American Medical Association 277, 15: 1224-1228.

Braun, D.
1998 "The role of funding agencies in the cognitive development of science." Research Policy 27: 807-821.

Braun, D.
2005 "How to govern research in the 'Age of Innovation': Compatibilities and incompatibilities of policy rationales." Pp. 11-37 in Lengwiler & Simon (Eds.), New governance arrangements in science policy. Berlin: WZB Discussion Paper.

Dasgupta, P. & David, P. A.
1994 "Toward a new economics of science." Research Policy 23: 487-521.
David, P. A.
2002 "The political economy of public science: A contribution to the regulation of science and technology." Pp. 33-37 in Smith (Ed.), The regulation of science and technology. Houndmills: Palgrave.
David, P. A., Mowery, D. C. & Steinmueller, E. W.
1994 "Analyzing the economic payoffs from basic research." Pp. 57-78 in Mowery (Ed.), Science and technology policy in independent economies. Boston: Kluwer.
De Boer, H., Enders, J. & Schimank, U.
2007 "On the Way towards New Public Management? The Governance of University Systems in England, the Netherlands, Austria, and Germany." Pp. 137-152 in Jansen (Ed.), New Forms of Governance in Research Organizations – Disciplinary Approaches, Interfaces and Integration. Dordrecht: Springer.
De Solla Price, D.
1984 "The science/technology relationship, the craft of experimental science, and policy for the improvement of high technology innovation." Research Policy 13: 3-20.
DFG
2002 "Deutsche Forschungsgemeinschaft: Perspektiven der Forschung und ihrer Förderung" (German research foundation: Perspectives of research funding). "Aufgaben und Finanzierung" (Responsibilities and sourcing) 2002-2006. Bonn.
2003 "Deutsche Forschungsgemeinschaft: Förder-Ranking 2003. Institutionen – Regionen – Netzwerke" (German research foundation: Funding-Ranking 2003. Institutions – Regions - Networks). "DFG-Bewilligungen und weitere Basisdaten öffentlich geförderter Forschung" (DFG-Grantings and further basic data on publicly funded research). Bonn.
2004 "Deutsche Forschungsgemeinschaft: Jahresbericht 2004. Aufgaben und Ergebnisse" (German research foundation: Annual report 2004. Activities and results). Bonn.
Etzkowitz, H. & Leydesdorff, L.
2000 "The dynamics of innovation: From National Systems and 'Mode 2' to a Triple Helix of university-industry-government relations." Research Policy 29: 109-123.
European Union
2002 Decision No 1513/2002/EC of the European Parliament and of the Council concerning the sixth framework program of the European Community for research, technological development and demonstration activities, contributing to the creation of the European Research Area and to innovation (2002 to 2006).
Funtowicz, S. O. & Ravetz, J. R.
1993 "The emergence of Post-Normal Science." Pp. 85-123 in von Schomberg (Ed.), Science, Politics And Morality. Scientific Uncertainty and Decision Making. Dordrecht: Kluwer.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. & Trow, M.
1994 The New Production Of Knowledge. The Dynamics of Science and Research in Contemporary Societies. London: Sage.

Glimmel, H.
2004 "Grand visions and lilliput politics. Staging the exploration of the 'Endless Frontier'." Pp. 231-246 in Baird, Nordmann & Schumeer (Eds.), Discovering the Nanoscale. IOS Press: Amsterdam.
Gluck, M. E., Blumenthal, D. & Stoto, M. A.
1987 "University-industry relationships in the life sciences: Implications for students and post-doctoral fellows." Research Policy 16: 327-336.
Godin, B.
1998 "Writing performative history: The new new Atlantis?" Social Studies of Science 28, 3: 465-483.
Grupp, H. & Schmoch, U.
1992 "Perceptions of scientification as measured by referencing between patents and papers. Dynamics in science-based field of technology." Pp. 73-130 in Grupp (Ed.), Dynamics of Science-Based Innovation. Springer: Berlin.
Heinze, T. & Kuhlmann, S.
2007 "Analysis of heterogeneous collaboration in the German research system with a focus on nanotechnology." Pp. 187-207 in Jansen (Ed.), New Forms of Governance in Research Organizations - Disciplinary Approaches, Interfaces and Integration. Dordrecht: Springer.
Hellström, T. & Jacob, M.
2000 "Scientification of politics or politicization of science? Traditionalist science-policy discourse and its quarrels with Mode 2 epistemology." Social Epistemology 14, 1: 69-77.
Hemlin, S.
2001 "Organizational aspects of mode 2/triple helix knowledge production." Pp. 181-200 in Bender (Ed.), Neue Formen der Wissenserzeugung (New forms of knowledge production). Frankfurt: Campus.
Hohn, H.-W. & Schimank, U.
1990a Konflikte und Gleichgewichte im Forschungssystem (Conflicts and equilibria in the research system). Akteurskonstellationen und Entwicklungspfade in der staatlich finanzierten außeruniversitären Forschung (Actor constellations and path dependency in publicly funded non-university research). Frankfurt: Campus.
Hoppe, H. C. & Pfähler, W.
2001 "Ökonomie der Grundlagenforschung und Wissenschaftspolitik." (Economics of fundamental research and science policy). Perspektiven der Wirtschaftspolitik (Perspectives in economic policy) 2, 2: 125-144.
Hullmann, A. & Meyer, M.
2003 "Publications and patents in nanotechnology. An overview of previous studies and state of the art." Scientometrics 58, 3: 507-527.
Internationale Kommission
1999 "Bericht der internationalen Kommission zur Systemevaluation der Deutschen Forschungsgemeinschaft und der Max-Planck-Institute: Forschungsförderung in Deutschland" (Report of the International Comission on system evaluation of the German Research Foundation and the Max-Planck-Institutes: Research funding in Germany). Hannover.

Jansen, D.
2007 "Governance of Research – Working towards Interdisciplinary Concepts." Pp. 109-133 in Jansen (Ed.), New Forms of Governance in Research Organizations – Disciplinary Approaches, Interfaces and Integration. Dordrecht: Springer.

Jacob, M.
2001 "Managing the Institutionalisation of Mode 2 Knowledge Production." Science Studies 14, 2: 83-100.

Johnson, A.
2004 "The end of pure science: Science policy from Bayh-Dole to the NNI." Pp. 217-230 in Baird, Nordmann & Schumeer (Eds.), Discovering the Nanoscale. Amsterdam: IOS Press.

Johnston, R.
1990 "Strategic policy for science." Pp. 213-226 in Cozzens, Healy, Rip & Ziman (Eds.), The Research System in Transition. Dordrecht: Kluwer.

Kealey, T.
1996 The Economic Laws of Scientific Research. Houndmills: Macmillan.

Kealey, T.
1998 "Why Science is Endogenous: a Debate with Paul David (and Ben Martin, Paul Romer, Chris Freeman, Luc Soete and Keith Pavitt)". Research Policy 26: 897-923.

Krippendorff, K.
2003 Content Analysis: An Introduction to its Methodology. Beverly Hills: Sage.

Kuhlmann, S.
2001 "Future governance of innovation policy in Europe – three scenarios." Research Policy 30: 953-976.

Martin, B. R.
2003 "The changing social contract for science and the evolution of the university." Pp. 7-29 in Geuna, Salter & Steinmueller (Eds.), Science and Innovation. Rethinking the Rationales for Funding and Governance. Cheltenham: Edward Elgar.

Mayer-Krahmer, F. & Schmoch, U.
1998 "Science-based Technology Research. University-industry Interaction in Four Fields." Research Policy 27: 835-851.

Metcalfe, J. S.
1997 "Science policy and technology policy in an competitive economy." International Journal of Social Economics 24, 7-9: 723-740.

Metha, M.D.
2002 "Nanoscience and nanotechnology: Assessing the nature of innovation in these fields." Bulletin of Science, Technology & Society 22, 4: 269-273.

Meyer, M.
2000 "Does science push technology? Patents citing scientific literature." Research Policy 29: 409-434.

Meyer, M.
2001 "The emergence of developer communities in a novel field of technology: A case of Mode 2 knowledge production." Pp. 147-162 in Bender (Ed.), Neue Formen der Wissenserzeugung (New types of generating knowledge). Frankfurt: Campus.

Meyer, M. & Persson, O.
1998 "Nanotechnology - Interdisciplinarity, patterns of collaboration and differences in application." Scientometrics 42, 2: 195-205.

Mintzberg, H.
1979 The Structuring of Organization: A Synthesis of the Research. Englewood Cliffs: Prentice-Hall.

Mulvey, J.
2002 "Can basic science be valued?" Pp. 58-67 in Smith (Ed.), The Regulation of Science and Technology. Houndmills: Palgrave.

Narin, F., Hamilton, K.S. & Olivastro, D.
1995 "Linkage between agency supported research and patented industrial technology." Research Evaluation 5,3: 183-187.

Narin, F., Hamilton, K.S. & Olivastro, D.
1997 "The increasing linkage between U.S. technology and public science." Research Policy 26: 317-330.

Nelson, R. R.
1959 "The Simple Economics of Basic Scientific Research." Journal of Political Economy 67, 3: 297-306.

Nowotny, H.
2005 "The changing nature of public science." Pp. 1-27 in Nowotny, Pestre, Schmidt-Aßmann, Schulze-Fielitz & Trute (Eds.), The Public Nature of Science Under Assault. Politics, Markets, Science and the Law. Berlin: Springer.

NSTC
2000 National Nanotechnology Initiative: The Initiative and Its Implementation Plan. National Science and Technology Council. Washington DC.

Pavitt, K.
2001 "Public Policies to support Basic Research: What can the Rest of the World Learn from US Theory and Practice? (And What They Should Not Learn)." Industrial and Corporate Change 10: 761-778.

Rip, A.
1992 "Science and technology as dancing partners." Pp. 231-270 in Kroes & Bakker (Eds.), Technological Development and Science in the Industrial Age. Dordrecht: Kluwer.

Roco, M. C. & Bainbridge W. S. (Eds.)
2001 Societal Implications Of Nanoscience And Nanotechnology. NSET Workshop Report. National Science Foundation. Arlington.

Rosenberg, N.
1990 "Why do firms do basic research (with their own money)?" Research Policy 19: 165-174.

Schäffer, W. (Ed.)
1983 Finalization in Science.The Social Orientation of Scientific Progress. Dordrecht: Reidel.

Schmidt, J. C.
2004 "Unbounded technologies: Working through the technological reductionism of nanotechnology." Pp. 35-50 in Baird, Nordmann & Schumeer (Eds.), Discovering the Nanoscale. Amsterdam: IOS Press.

Schummer, J.
2004a "Multidisciplinarity,interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology." Scientometrics 59, 3: 425-465.

Schummer, J.
2004b "Interdisciplinary issues in nanoscale research." Pp. 9-20 in Baird, Nordmann & Schummer (Eds.), Discovering the Nanoscale. Amsterdam: IOS Press.

Shinn, T.
1999 "Changes or mutation? Reflections on the foundations of contemporary science." Social Science Information 38, 1: 149-176.

Slaughter, S. & Leslie, L. L.
1997 Academic Capitalism: Politics, Policies, and the Entrepreneurial University. Baltimore: Johns Hopkins University Press.

Wald, A., Franke, K. & Jansen, D.
2007 Reforms and Scientific Production – Evidence from German Astrophysics. Pp. 211-232 in Jansen (Ed.), New Forms of Governance in Research Organizations – Disciplinary Approaches, Interfaces and Integration. Dordrecht: Springer.

Weingart, P.
1997 "From ''finalization' to 'Mode 2': Old wine in new bottles?" Social Science Information 36, 4: 591-613.

Wilts, A.
2000 "Forms of research organization and their responsiveness to external goal setting." Research Policy 29: 767-781.

Wissenschaftsrat
2000 "Thesen zur künftigen Entwicklung des Wissenschaftssystems in Deutschland" (Theses on the future development of the German science system). Köln.

Wissenschaftsrat
2002 "Schwerpunkte der Forschung an Hochschulen: Stellungnahme zum Programm der Sonderforschungsbereiche" (Emphases of university research: Comments on the programs of the Collaborative Research Centres). Essen.

Wissenschaftsrat
2003 "Strategische Forschungsförderung. Empfehlungen zu Kommunikation, Kooperation und Wettbewerb im Wissenschaftssystem" (Strategic research funding. Recommendations on communication, cooperation and competition in the research system). Essen.

Andreas Wald
European Business School, Germany
andreas.wald@ebs.edu