IV. Analysis of Heterogeneous Collaboration in the German Research System with a Focus on Nanotechnology

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The German research system is functionally differentiated into various institutional pillars, most importantly the university system and the extra-university sector including institutes of the Helmholtz Association, the Max Planck Society, the Leibniz Association and the Fraunhofer Society. While the research organizations' heterogeneous institutional profiles are widely regarded as a key strength of the German research landscape, tendencies toward segmentation and institutional self-interests have increasingly impeded inter-institutional collaboration. Yet, in young and highly dynamic fields, many research breakthroughs are stimulated at the intersection of established scientific disciplines and across fundamental and applied technological research. Therefore, inter-institutional collaboration is an important dimension of the performance of the German research system. There is tension between the need for effective inter-institutional collaboration on the one hand, and the governance structures in the public research sector on the other hand.

The paper presents preliminary results of an ongoing DFG project on collaborations between the various research institutions in Germany, particularly in the field of nano S&T. It introduces key facts of the German research system including institutional dynamics between 1990 and 2002. It discusses rationales for cooperative research relationships and elaborates on institutional factors that either facilitate or interfere with the transfer of knowledge and expertise between research organizations. For this purpose, the paper refers to a "governance cube" as a heuristic tool that captures three institutional dimensions which are important in facilitating heterogeneous research cooperation.

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1. Introduction

The German research system is functionally differentiated into various institutional pillars, most importantly the university system and the extra-university sector including institutes of the Helmholtz Association (HGF), the Max Planck Society (MPG), the Leibniz Association (WGL) and the Fraunhofer Society (FhG). Within the extra-university research sector, organizations have – to a certain extent – developed functional monopolies in particular research domains, between which neither competition nor research collaboration have traditionally been sought. Such research domains include fundamental research (Max Planck Society), applied contract research (Fraunhofer Society) and big-science research facilities (Helmholtz Association). Since the 1990s, the German research system has come under considerable pressure. A high-level evaluation committee pointed to the "segmentation of the science and research system in Germany" and the "dominance of institutional self-interests", which "reduces the utilization of possible synergies" (Internationale Kommission 1999: 7). According to the evaluators, institutional research profiles are one of the key strengths of functionally differentiated research systems if they are utilized accordingly. This could be achieved by better connecting disciplinary research in the universities and interdisciplinary research in the extra-university sector, or by devoting more effort into linking basic and applied research activities to one another.

The tension between the need for effective inter-institutional collaboration, on the one hand, and the governance structures in the public research sector, on the other hand, can be discussed at the level of research systems (macro perspective), but also at the level of research institutes in particular fields (meso perspective). Both perspectives are addressed in this article, but the major focus is on nano science and technology (S&T), a research field where this tension is pertinent. In this young and highly dynamic field, many research breakthroughs are stimulated at the intersection of established scientific disciplines and across fundamental and applied technological research. It is in such fields that new scientific sub-fields emerge, and where considerable potential for technological innovations can be found. We think that analyses of fields like nano S&T allow for a better understanding of the tension between institutional rigidities and research dynamics in the public research sector.

The phenomenon of *heterogeneous collaboration* in the German research system (= research collaboration across institutional boundaries) has not been given due attention thus far in the sociology of science literature. While the institutional interfaces between university and private sector research are comparatively well understood (Schmoch 2003; Meyer-Krahmer and Schmoch 1998), the interfaces between (and within) public and semi-public research organizations have hardly been examined. Recent publications on the German research system investigate primarily interdisciplinary cooperation (Röbbecke et al. 2004) and the research system's overall path of modernization (Hohn 2005). Only a few studies deal in detail with the institutional framework of and collaborative patterns within the

German research system (Hohn and Schimank 1990; Hohn 1998; Laudel 1999). However, the latter studies refer primarily to the 1980s and early 1990s. Consequently, only little is known about current collaboration between university research and extra-university research institutes and among institutes within the extra-university sector.

This article presents preliminary results of an ongoing project,[3] It draws on multiple data sources such as annual reports of German research institutions, internal reports and communications, co-publication analyses and macro research statistics. Most importantly, we conducted about 30 in-depth interviews in 2004 and 2005 with representatives of all extra-university research organizations (except for the Leibniz Association, WGL), the German Federal Ministry for Education and Research (BMBF), institute directors at universities and extra-university institutions, senior researchers and junior group leaders, focusing on nano S&T as an example.[4]

Section 2 provides key figures about the German research system including data on recent institutional change. Section 3 introduces the field of nano S&T and discusses why effective inter-institutional collaboration is an important issue. Section 4 provides a sketch on current collaborative activities in nano S&T across research institutions in Germany. Section 5 discusses rationales for cooperative research relationships. In Sections 6 and 7, we elaborate on institutional factors that either facilitate or interfere with the transfer of knowledge and expertise between research organizations. Section 8 summarizes our findings and provides an outlook on research desiderata.

2. Recent institutional dynamics in the German research system

Let us first consider some key facts about German research institutions in order to understand why *heterogeneous research collaboration* poses a particular challenge for the German research system. As shown in Table 1, the university sector (excluding social sciences and humanities) is substantially larger than the extra-university sector in terms of personnel (B), but has a much smaller research base in relative terms (C). Nevertheless, university researchers are highly productive, as displayed in their share of all three output categories (E, F, G). Within the extra-university sector, the Max Planck Society has the strongest scientific profile: MPG institutes recruit only 2.6 per cent of the German research personnel (excluding social sciences and humanities), but they account for 10.0 per cent of the German

[3] The project "Governance of the Cooperation of Heterogeneous Partners in the Research and Innovation System" is part of the DFG Research Group "Governance of Research" (http://www.foev-speyer.de/governance/).

[4] The main focus of our analyses is on the university sector, MPG, FhG and HGF. WGL institutes are not dealt with in detail.

SCI papers (E) and 34.0 per cent of all German *Science* and *Nature* articles (F). In contrast, FhG institutes publish much less in SCI, but have the highest relative output of patent applications (G). FhG institutes primarily conduct contract research for companies, but also public agencies. Their core funding is substantially lower than that of all other research institutions (D). In terms of research output, universities are located between the distinct institutional profiles of MPG and FhG.

The Helmholtz Association has traditionally had an institutional mission in big science research facilities and key technology development and thus stronger ties to the federal state. Although comparable to the MPG in its high level of institutional funding (D) and equipment level per researcher (C), its relative productivity is substantially lower (Table 1): 7.3 per cent of the German research personnel (B) publish 7.5 per cent of the German SCI papers (E), 13.5 per cent of all German *Science* and *Nature* articles (F) and file 13.3 per cent of all patent applications of the public sector research institutions (G). The HGF has implemented a new internal budget allocation program in 2001, the most important aim of which is to consolidate its thematic portfolio and to strengthen its institutional profile (HGF 2004). WGL institutes are also an important part of the German research landscape. Their overall relative research performance (4.2% of SCI publications, 2.4% of research personnel) is between the Helmholtz and Max Planck, but the Leibniz Association has not yet developed an institutional profile, neither in terms of fundamental (F), nor with regard to applied research (G).

Table 1: Key facts of the German research system

	A	B	C	D	E	F	G
	Budget 2001 (€ m)*	Research Personnel 2001 (FTE)*	A/B	Institutional Funding 2003	Total SCI Papers 2000–2002	Total Science and Nature Papers 2000–2002	Total DPA, WPI Patent Applications 1999–2001
Universities	10,119 (56.9%)[1]	100,455 (71.3%)[1]	0.101	--[2]	145,847 (71.7%)	474 (51.4%)	6,394 (70.7%)
Helmholtz Research Centers (HGF)	2,288 (12.9%)	10,252 (7.3%)	0.223	78%	15,352 (7.5%)	125 (13.5%)	1,206 (13.3%)
Max Planck Society (MPG)	938 (5.3%)	3,692 (2.6%)	0.254	80%	20,414 (10.0%)	314 (34.0%)	245 (2.7%)
Leibniz Association (WGL)	568 (3.2%)	3,348 (2.4%)	0.170	70%	8,558 (4.2%)	44 (4.8%)	188 (2.1%)
Fraunhofer Society (FhG)	947 (5.3%)	5,647 (4.0%)	0.168	39%	1,988 (1.0%)	2 (0.2%)	1,011 (11.2%)

Source: SCI, WPINDEX, PATDPA (host: STN), BMBF (2005).
[1] including teaching; [2] no figures available.
* Excluding social sciences and humanities. Not all German research institutes are covered, therefore A and B do not add up to 100 per cent. Non-fractional counts in E, F and G.

The various institutional positions of MPG, HGF, FhG and Leibniz have been mapped in Figure 1 that shows a cross-tabulation of two major output variables of German research institutions: SCI publications and DPA/WPI patent applications (both relative to 100 R&D staff) between 1990 and 2002. Figure 1 displays an institutional space (or system of coordinates) at a highly aggregated level in which multiple research profiles of research organizations can be located. Basic science (upper left area) and technology-driven research (lower right area) are positions occupied by the Max Planck Society and the Fraunhofer Society respectively.

Two trends are clearly visible in Figure 1: first, all institutions substantially increased their productivity between 1990 and 2002, as is visible in their move both towards the right and upwards, indicating higher outputs per input of R&D staff. This is a clear indication of the high pressure on the research system to demonstrate higher output efficiency. Despite a substantial decrease in public sector research funding,[5] scientists in 2002 produced significantly more research papers and patent applications than in 1990.[6] Second and more importantly, shifts of research organizations in the direction of technological research (move to the right) are more pronounced than movements in the direction of scientific competency (upward move). This development implies a decreasing institutional differentiation in the German research system in two ways. First, institutes that did not carry out technological research in the early 1990s apparently do so today. Second, institutes whose core competence has traditionally been in technology research have come under considerable pressure. Consequently, today the Fraunhofer Society faces substantial competition from various research institutions in its traditional domain of technological research, as shown by their decreasing relative patent output between 1995–1998 and 1999–2002.

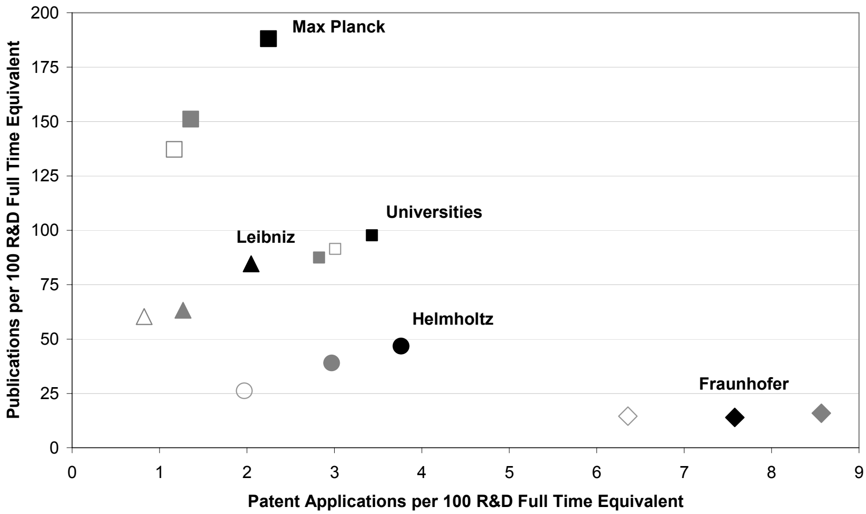
Despite considerable dynamics, Figure 1 does not yet indicate fundamental changes in the landscape of German research institutions. One should note, for instance, that the Max Planck Society, the Leibniz Association and the university sectors show an increase in scientific productivity over time. For the MPG, in particular, the trend towards more patenting has been accompanied by a substantial increase in scientific publications. Furthermore, there is no direct overlap between research organizations' positions in the institutional space of research profiles. The interesting point is, however, that current pressures on the research system have induced competition between formerly protected research domains, but have

[5] Between 1992 and 2002, federal spending stagnated at 89.5 per cent of the 1991 R&D investment level (on average). Likewise, the number of tenured university professors was cut from 25,000 to 23,000 between 1995 and 2005. At the same time, the scientific labor force in the public research sector stagnated (BMBF 2005: Tables 20, 21, 38; Deutscher Hochschulverband Press Release 11/2005; Eurostat 2003: 62).

[6] Although this conclusion refers to publications and patent applications only, these two indicators are relatively robust and have been widely applied in S&T studies (Moed et al. 2004). We do not think that "output efficiency" is necessarily the same as "research efficiency". Because we measure only output variables, and not research quality variables, wide-ranging conclusions on the overall efficiency of German research institutions should not be drawn from Figure 1.

not increased inter-institutional cooperation. The problem of institutional segmentation, as observed by the high-level evaluation committee in 1999 (Internationale Kommission 1999: 7), appears even more severe today than it was in the 1990s. In accordance with Figure 1, our interviews suggest that both sustained budget cuts and pressure on output efficiency have increased competition for scarce research funds and led to a decreased utilization of possible synergies within the German research system.

Figure 1: Institutional dynamics in the German research system between 1990 and 2002



Source: SCI, WPINDEX, PATDPA (host: STN), Computations by authors.
White shade = 1990–1993, gray shade = 1995–1998, black shade = 1999–2002. For universities the scaling factor is 50 R&D FTE (instead of 100) because their institutional mission embraces both teaching and research. All data exclude social sciences and humanities. Numbers are annual averages. Example: in the period of 1999–2002, a university scientist published one article per year on average, while every 30th university scientist filed a patent. The Research Centre for Computational Sciences (GMD), which was transferred from Helmholtz to Fraunhofer in 2001, is not included in the data.

3. Why heterogeneous collaboration is important in the German research system: the case of nano S&T

Collaboration across institutional boundaries is particularly important in young and dynamic fields of science and technology, where many research breakthroughs are stimulated at the intersection of established scientific disciplines and across fundamental and applied technological research. It is in such fields that both new scientific sub-fields emerge and a considerable potential for technological innovations can be found. Unlike others, we do not claim that such research fields are more important than scientific disciplines, or that they will even provide a substitute for existing institutions in science and technology (Nowotny et al. 2001). Rather, we think that analyses of fields like nano S&T allow a better understanding of the tension between institutional rigidities and research dynamics in the public research sector.

Consider that the organizational infrastructure dedicated to the fundamental understanding of certain nano-scale properties (= basic research) is institutionally separated from the organizational infrastructure for modifying and functionalizing certain nano-scale phenomena (= applied technological research). MPG institutes on the one hand and FhG institutes on the other hand, are cases in point as they follow different research missions and operate under different governance regimes, which have often impeded collaboration across institutional boundaries. However, in the field of nano S&T – and apparently in other research fields too – various researchers have found it useful to pool these different competencies. As one Max Planck director put it:

> "I have pledged for more than ten years at the MPG and FhG headquarters to foster institutionally cross-organizational collaboration. (…) There are clearly different tasks to do, but as science and technology evolve, it is always like this: there is overlap at the margin where one institution comes close to another one and where collaboration would be useful. In this margin one should invest money in order for these institutions to work together" (Translation by authors).

To be sure, this does not only pertain to MPG and FhG, but also to institutes of the HGF, WGL and universities. However, MPG and FhG are interesting examples in that their research missions are distinct and fundamentally different (Figure 1). While MPG institutes are institutionally located at the core of fundamental science, FhG institutes are institutional hybrids bridging the academic world and industry (Heinze 2005).

The field of nano S&T is predestined for what we call heterogeneous cooperation because it provides more opportunities for collaborative research activities between mutually interdependent research units than more mature and established fields. Nano S&T is an interdisciplinary and expanding field dealing with the characterization, activation, modification and functionalization of various phenomena at the nano-scopic level (Heinze 2004, 2006; Hullmann and Meyer 2003). Both the fundamental understanding of structures and processes at the atomic and molecular scale and the utilization and control of nano-scale phenomena for technical purposes and commercial products have progressed considerably in recent years. Not only scientists are intrigued by the fascinating opportunities of this dynamic field, but also policy-makers believe nano S&T to be one of the key technologies of the 21st century.

Among its various sub-fields, we have focused specifically on nano-electronics and nano-interfaces. *Nano-electronics* is an emerging sub-field including topical areas such as *carbon nano-tubes* and *wafer bonding*. Carbon nano-tubes have interesting electrical properties, which are scientifically relevant for molecular electronics and biophysics; but at the same time carbon nano-tubes have high potential for future integrated circuits and, thus, the computer industry. Wafer bonding is another nano-electronical area where epitaxy methods are used to allow faster electron transmission within silicon structures, which are highly relevant for enhancing computer processor speed. *Nano-scale interfaces* is a second emerging field within nano S&T, spanning topical sub-areas such as *nano-capsules* or *nano-sensors*. Based on thin film colloidal chemistry methods, nano-capsules have considerable potential to be used as carriers for targeted medication. Similarly, the fundamental understanding of reactivity of nano-surfaces allows the construction of biocompatible and portable nano-sensors.

4. Collaborative research activities in nano S&T

Our methodical approach is to analyze research organizations with a high degree of thematic and functional interdependence in the two sub-fields of nano S&T. Therefore, we have systematically searched the field of nano S&T for inter-institutional collaborative research activities at both the macro- (research system) and the meso-levels (research institutes). First of all, a comprehensive check of nano-publications and collaborative research projects was carried out. Furthermore, we conducted interviews primarily with researchers who were experienced with extra-mural collaborations. Interviewees with few external contacts were also included, but only to a limited degree. Hence, our interview sample is selective. In hindsight, this approach proved to be valuable because interviews with researchers who have considerable experience with external collaborations are at a higher risk to experience tensions and rigidities that are built into the governance regimes of the various research institutions. Thus, they are the proper target group for the research question under examination (see Sections 6 and 7).

About 60 per cent of all German nano S&T publications in the Science Citation Index (SCI) can be attributed to university researchers, followed by the MPG institutes, which account for 17 per cent of all publications. HGF centers publish 8.5 per cent of all nano S&T articles, while FhG institutes have the lowest share of all extra-university research centers (Table 2: A, B). The majority of domestic research collaborations, as measured by co-publications at the macro-level, are observed between universities and the extra-university research sector, while co-authorship relations within the extra-university sector amount to only nine per cent of all co-publications.[7] In total, MPG institutes collaborate most frequently with universities, followed by the HGF and the FhG (Table 3). It is also conspicuous that the HGF and in particular, FhG institutes are more oriented toward the national research system than MPG and university researchers. Compared to their

[7] Although co-publications map collaborative activities only partially (Katz and Martin 1997; Laudel 2002), they are well-established indicators in scientometrics (Melin and Persson 1996; Bordons and Gómez 2000; Glänzel and Schubert 2004; Newman 2004).

overall publication output in nano S&T, 40 per cent of all HGF publications and 55 per cent of FhG publications show extramural collaboration in Germany, while only 29 per cent of all MPG publications and only 24 per cent of all university publications involve domestic research collaborators (Table 2: C). This finding is further substantiated when international collaborations are taken into account. FhG research is least international in scope; their international co-publications are about half the number of domestic ones. By contrast, MPG and university scientists copublish more with foreign researchers, both in absolute and relative terms. Compared to all other research institutions, MPG and university researchers are most integrated in the international system of science. HGF research centers are less internationalized than MPG institutes in nano S&T relative to their domestic co-publications (Table 2: G).

Table 2: Publication output and co-publications of German research institutions in nano S&T, 1999–2003

	A	B	C	D	E	F	G
	Publications	%	Domestic Co-publications	C/A %	International Co-publications**	E/A %	E/C %
Universities	7,985	59.3	1,878	23.5	2,446	30.6	130.2
Max Planck Society (MPG)	2,309	17.2	660*	28.6	825	35.7	125.0
Helmholtz Association (HGF)	1,143	8.5	461*	40.3	370	32.4	80.3
Fraunhofer Society (FhG)	249	1.9	137*	55.0	64	25.7	46.7
Others	1,770	13.2	-	-	-	-	-
Total (non-fractioned count)	13,456	100	-	-	-	-	-
Total German publications	12,016	-	-	-	-	-	-

Source: SCI (host: STN), Computations by the authors.
* Not including intra-institutional co-publications, therefore underestimated.
** Top 10 countries with which German researchers co-publish most often: United States, the United Kingdom, Switzerland, Russia, France, Austria, Japan, Italy, the Netherlands, Sweden (Glänzel 2001: 85).

Table 3: Co-publications between German research institutions in nano S&T, 1999–2003

	FhG	MPG	Universities	HGF
FhG		18 (3)	107 (10)	12 (3)
MPG	18 (13)		568 (54)	74 (16)
Universities	107 (78)	568 (86)		375 (81)
HGF	12 (9)	74 (11)	375 (36)	

Source: SCI (host: STN), Computations by the authors; in brackets: column per cent

At the meso-level, we identified *formal project collaborations* by systematically screening German Research Foundation (DFG) and German Ministry for Education and Research (BMBF) projects. The DFG has been funding basic research projects in the areas of *nano-colloids and -polymers, nano-materials and optical nano-technologies.* These programs have been extended in size and scope over the last decade and, thus, have provided more opportunities for collaborative activities to develop.[8] In the applied research funding of BMBF, we found collaborations in the fields of *nano-polymers, semiconductors, nano-materials and laser*. Some of these projects are part of the two broad sub-fields mentioned in the above and they were selected for in-depth interviews.

Other types of formal collaborations include *cooperation contracts* between research institutes specifying the use of research instrumentation and interchange of personnel. We also found *junior research groups* at the intersection of institutes that were institutionally located at one institution, but personnel and instrumentation costs were shared. Furthermore, *education of junior researchers* is an institutional vehicle for collaborations not only between universities (where junior staff receive their doctoral degree) and the extra-university sector (where they carry out their projects), but also within the extra-university sector, for instance via *Max Planck International Research Schools* where doctoral students of FhG institutes are enrolled.

Informal collaborations include *meetings of the heads of institutes* whose function is information sharing and preparation of collaborative research proposals; also *sharing of doctoral students* that travel between sites and carry out experiments. *Professional mobility* – although apparently underdeveloped in the German research system – also plays a crucial role in facilitating opportunities to meet new researchers and, consequently, to extend the scope and breadth of scientific contacts. Researchers with inter-organizational career tracks or with a record of visiting fellowships have accumulated informal contacts to other research institutions that help in building consortia at certain times and for particular purposes.

[8] The BMBF provides publications on coordinated programmes at its website (see www.bund.bmbf.de). For more details on the development of coordinated DFG programmes, see Greve (2005).

5. Rationales for research collaboration

A proper understanding of the governance of research collaboration in a highly differentiated research system needs to take into account scientists' rationales for engaging in collaborative activities. Generic motives for research collaboration include curiosity, advancement of knowledge, sharing excitement of a research area with other scientists or intellectual companionship (Katz and Martin 1997; Beaver 2001). These motives are anchored in what Luhmann (1991) describes as "cognitive style of expectation". However, they do not specify why particular scientists would collaborate with other scientists at a given time. For the field of nano S&T, we empirically validated *particular collaboration rationales* that will be briefly discussed in the following paragraphs (Figure 2).

Figure 2: Motives and reasons to engage in inter-institutional research collaboration

1) Expansion of research capacity
   a) Need for complementary knowledge and expertise
   b) Access to equipment and instrumentation
   c) Availability of research funds
2) Improving current research
   d) Keeping research activities focused/preventing intellectual fragmentation
   e) Learning new skills or techniques
3) Realizing institutional synergies
   f) Universities → extra-university institutes: access to better facilities, research topics
   g) Extra-university institutes → universities: access to students
4) Enhancing visibility and prestige
   h) Max Planck as label for basic research
   i) Fraunhofer as label for applied research

The first set of rationales is the *expansion of research capacity* which embraces (a) the need for complementary knowledge and expertise; (b) access to equipment and instrumentation; and (c) the ability to build consortia that compete for funding. An example for (a) is an ongoing collaboration between two groups, one of which is specialized in the electrical measurement of nano wire characteristics, while the other group is highly knowledgeable in respective optical measuring techniques. Both knowledge domains have been fruitfully combined over time and, thus, have led to many co-authored publications. Combining complementary knowledge and expertise expanded both groups' capacities to address new questions and to establish new thematic areas. An example for (b) is one group interested in solving a particular research question on metallic nano-particles and two instrumentation groups (synchrotron, molecular beam lithography) that are interested in learning more about the various possibilities of their complex machinery. There were many examples for (c). As the expansion of research capacity requires additional funding and because many research questions (due to their complexity) cannot be addressed by single groups alone, researchers have an incentive to build project consortia that compete collectively for third party funds.

A second set of collaboration rationales is anchored in strategies to *improve current research*. It includes (d) keeping research activities focused and (e) learning new skills or techniques. Examples for (d) and (e) are three chemistry groups that are embedded in institutes with strong physics capacities. Such embedding has several benefits, most importantly access to new research questions generated outside one's own specialty, opportunities to get acquainted with new methods and instrumentation, but also continuous scrutiny from the physicists with regard to interpretation of experimental results. The DFG funding of this collaborative research center has been characterized by our interviewees unanimously as truly helpful in this regard because it is viewed as an institutional vehicle for providing a broader disciplinary context and for working against intellectual fragmentation.

Thirdly, *realization of institutional complementarities* is an important collaboration rationale. (f) Universities seek cooperative relations with extra-university institutes in order to get access to facilities, instrumentation and research topics, while (g) extra-university institutes depend on access to students and junior researchers. Institutional complementarities also exist between groups specialized in either basic or applied research. FhG institutes usually provide considerable expertise in the testing and development of reliable technical processes, while university or MPG groups have access to the latest knowledge at research frontiers. In the areas of nano-electronics and nano-interfaces, such institutional profiles have been found complementary for both sides. On the one hand, there are novel scientific approaches in wafer bonding and nano-polymers that need considerable engineering before their industrial application becomes feasible. On the other hand, problem-solving on the engineering side has generated new research questions that are valuable for a fundamental science perspective.

Fourthly, research institutions seek collaborations in order to *enhance their visibility for scientists and companies in the field*. We identified cases where collaborators related to each other because of their differential research profiles that in turn are anchored in differential organizational missions. (h) There are MPG institutes (not the majority!) who use their Fraunhofer collaborations to signal to industrial companies their openness for applied technological research questions (which traditionally lie outside their core competency). Contacts to larger companies can be beneficial for MPG institutes in terms of additional funding, but they are also valuable with regard to future job opportunities for doctoral students and post docs. (g) Vice versa, a number of FhG institutes (not the majority!) use contacts to MPG institutes to signal scientific prestige to academic researchers in university departments and other basic science facilities. Furthermore, because the Fraunhofer funding regime does not allow substantial basic research activities, such contacts signal access to research frontiers, which – in combination with engineering and reliability testing capacities – might be an incentive for companies to fund contract research in FhG institutes. The difference between Max Planck and Fraunhofer institutes is that the former use signaling primarily to attract industrial recognition, while the latter attempt to draw either academic or industrial attention to its research activities.

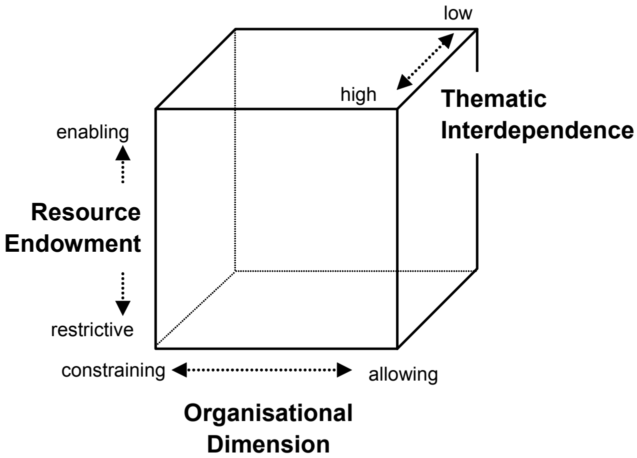
6. Institutional factors conducive to heterogeneous research collaboration

Rationales for research collaboration across institutional boundaries are an important starting point for understanding the institutional factors that facilitate collaborative activities. In order to examine the governance of heterogeneous research collaboration in more detail, we refer to a *governance cube* as a heuristic tool (Figure 3). Generally speaking, the concept of *governance* refers to analytically distinguishable forms of institutional coordination of autonomous, but interdependent actors.[9] Hierarchy, competition, network, association and community are such ideal types of governance capturing the *rules of a game* at a highly generalized level (Hollingsworth and Boyer 1997; Lütz 2003). In reality, these governance forms are often interconnected, thus forming *governance regimes*. Benz argues, for instance, that actors have to find out how to cooperate with competitors or to compete with partners in networks, to negotiate an agreement under tight organizational constraints or to find approval for the outcome in external arenas in their own organization or group (Benz 2007). The *governance cube* takes up notions of both governance forms and governance regimes, but is specifically tailored to the research question of *heterogeneous research collaboration*.

The dimension of *thematic interdependence* captures the extent to which research activities build on each other and how the cognitive structure of research fields impinges upon the work organization of research. As explained in Section 5, we have identified various cognitively interdependent, but institutionally separated research groups in nano-electronics and nano-interfaces. According to Figure 3, these groups and organizations tend to be "highly" interdependent both in terms of the interdisciplinary character of work, but also with regard to the degree to which work results from fundamental and more applied research efforts built on each other. The *organizational dimension* depicts the governance regimes of both the university and the extra-university sector including Helmholtz, Max Planck and Fraunhofer. On the level of single research units (institutes, research groups), the organizational dimension embraces variables such as internal differentiation, permeability of communication across levels of hierarchy, career incentives or research missions. *Resource endowment* includes the quantity and the quality of staff and equipment as well as the funding structure of research units (Figure 3).

[9] Organizations are conceived of as "corporate actors".

Figure 3: Governance dimensions of research collaboration



I. Thematic Interdependence: (1) Interdependency of research activities (e.g., extensive division of labor); (2) Integration of research results (e.g., methodological, disciplinary, by subject). The degree of intellectual interdependence can vary between high and low, both between research units (e.g., institutes, research groups) and on the level of research fields.

II. Organizational Dimension: (1) Degree of centralization and formalization of decisions and decision processes (e.g., regarding reward structures, personnel policy, young researchers, career pattern); (2) Relationship between organizational micro-, meso- and macro-levels (e.g., deep or flat hierarchies, leverage and permeability across levels); (3) Cultural integration (e.g., self-images, taken-for-granted rules, missions). The organizational dimension varies between constraining and allowing.

III. Resource Endowment: (1) Financial structure (e.g., level of institutional and third party funding, allocation mechanism); (2) Infrastructure (e.g., buildings, apparatus, instruments, computing capabilities); (3) Human resources (e.g., qualified personnel, job mobility). The resource endowment can be conceived of as either restraining or enabling.

I. draws on Whitley (2000), II. and III. on Hohn and Schimank (1990).

By applying the *governance cube* we identified a number of institutional factors which are potentially important in facilitating heterogeneous research cooperation. As far as the intellectual dimension is concerned, *distinct thematic profiles* of research groups (and research institutions) are of paramount importance as they channel attention, thereby supporting search processes and decision-making (exante) and increasing mutual benefits from collaborative activities (ex post). This finding is in accordance with the fact that one of the major rationales for collaborative activities is the need for complementary knowledge and expertise. It also fits our finding that researchers prefer collaborators with a reputation for a certain expertise that proves valuable in research consortia's competition for additional research grants (see Section 4). Distinct profiles are also important with respect to the organizational dimension, but here they pertain to the "research mission" of groups or institutes. Such *distinct research profiles* include basic versus technology-driven research, but also the capability to conduct highly reliable routine research or the capacity to produce scientific breakthroughs continuously. Organizational and intellectual profiles need not overlap.

Further on the organizational dimension, *processes for selecting qualified, mobile research personnel* endow organizations with a basic understanding of different institutional perspectives. This organizational capacity seems highly valuable in a functionally differentiated research system, such as the German one. In addition, *research leadership* facilitates collaborative activities across institutional borders. Research leadership implies the articulation and enactment of mid-term research goals, which enable external coalition building. It also involves the proactive use of windows of opportunity and the ability to shift the research agenda in the direction in which the research field is moving. Windows of opportunity include strategies to access new external funding, revisit internal research priorities, but also the ability to take advantage of organizational shifts (e.g., availability of resources) that might otherwise be absorbed by competitors. Research leadership is in accordance with the rationales of expansion of research capacity and improvement of current research. Finally, *effective administration* (at the organizational level) supports research collaboration, for instance, by making decisions promptly, by not consuming resources above a certain threshold ("overhead"), or by allowing flexible interchange of resources including mobility of personnel. The professional logic of such an administration is closely connected to the institutional logic of the research group or organization.

With regard to resource endowment, our analyses suggest that research collaboration is facilitated when partners have *sufficient core funding* at the group or organizational level. Such funding is obviously a prerequisite for developing *research profiles*, which support search processes and increase mutual benefits from research collaboration.[10] However, *third party funding also stimulates cooperative behavior,* as external collaboration is requested in many funding programs. One of the major benefits of third party funding is that it helps research groups to keep their research focused and to coordinate various research agendas. Institutes with a high level of core funds compete for third party funding only if research leadership decides to do so. MPG and HGF departments, for instance, which traditionally enjoy very high levels of core funding (Table 1), tend to be less involved in extra-mural collaborative research projects if their research leaders do not actively seek third party funding.

We believe that core funding and third party funding have to be balanced in some way in order to induce collaborative activities in the field of nano S&T. But

[10] Findings from our interviews also suggest that sufficient core funding is a prerequisite for engaging in research venues that are intrinsically risky – a finding that pertains in particular to research creativity.

instead of suggesting an "optimum formula" that would be misleading anyway, we invite the reader to consider *two types of resource flexibility* that appear to be important in facilitating collaborations. First, the *flexible allocation and interchange of resources between institutes* supports collaborative activities because they are specifically tailored to conducting research effectively. One example is scientists who, while moving from one institution to another, take their research projects with them. Another example is that project funding allocated to a Max Planck institute is shifted to a university institute because a collaborating doctoral student has access to special equipment at the university and thus can carry out the work more effectively. A third example is collaboration contracts between extra-university institutes arranging mutual support in instrumentation or library services.

Second, *allowing non-standard funding structures within a research department or group* is a kind of institutional flexibility that enables extra-mural collaborative activities. We conducted interviews with junior group leaders in HGF and MPG departments whose research activities were to a large extent embedded in collaboration projects with external partners, while other groups in their departments had a high level of core funding. Likewise, we interviewed a young scientist in a Fraunhofer institute who is leader of a junior group that enjoys much higher core funding than other departments. We cannot judge at present if such hybrid constellations are more productive than homogeneous modes of institutional funding, but we believe that if such groups were not supported, many collaborative ties would not have been established at all. This consideration brings our attention to adverse factors that interfere with heterogeneous research cooperation. The following section discusses such institutional factors in a preliminary fashion.

7. Institutional factors interfering with heterogeneous research collaboration

With regard to the organizational dimension, *stereotypes and prejudices* play an important role in thwarting cooperation between heterogeneous research organizations. Examples of such stereotypes that we validated in our interviews are as follows: HGF researchers have a reputation for being slower and less productive than average, while MPG scientists are viewed as those with lavish laboratories and sometimes arrogant attitude towards researchers from other research organizations. In contrast, FhG researchers are often equated with industry because they focus primarily on money instead of scientific quality. Furthermore, university researchers are often regarded as conducting research projects in a chaotic and even unprofessional way. These examples are not necessarily based on experience, but often on hearsay, because both low overall job mobility and low degree of formal and informal inter-institutional collaborations have provided only limited opportunities for experience with other research organizations (see Section 3).

Second and in contrast to the first factor, heterogeneous collaboration can be hampered by *incompatible working routines* anchored in divergent organizational missions. Interviewees from Fraunhofer institutes and Max Planck institutes agreed in their assessment that straightforward interaction between what they called the “engineering attitude” of Fraunhofer researchers (i.e., to produce a project result within a finite time frame and a finite sum of money) and the “playing attitude” of Max Planck researchers (i.e., searching without restrictions or “picking flowers”) can be bothersome if there is no moderator or translator. This once again raises the issues of job mobility and research leadership, because in our case studies where divergent working routines are being used effectively for both sides, we found either researchers with a mobility record or active research leadership at the level of institute directors.

Third, *lack of interface management* seems a common problem for researchers who do not have the means or resources to organize follow-up activities in cases when they have results that might be relevant for other research institutions. It was only very recently that the headquarters of the Max Planck Society and the Fraunhofer Society started a dialogue on pooling expertise and know-how in various research areas, among them nano S&T. The president of the Max Planck Society called in his 2004 annual meeting speech for stronger institutional ties between fundamental and applied research, particularly between the MPG and the FhG (Gruss 2004: 19f). This approach, however, has not been adopted by either the Helmholtz Association or by the Leibniz Association.

Regarding the *resource endowment dimension* in the governance cube (Figure 3), our analysis suggests that *sustained budget cuts over the last decade*, particularly in the university system, have had negative effects on the ability of research groups to engage in inter-institutional collaboration. As outlined above, public sector research funding in Germany, particularly of the university sector, decreased substantially in real terms between 1991 and 2000. This situation was counterbalanced only partly by the comparatively good funding situation in the field of nano S&T.[11] Prolonged budget cuts will have both immediate and mid-term effects on the abilities of researchers to conduct research collaboratively and, thus, the capacity of the research system to sustain a certain level of cognitive innovations resulting from effective transfer and exchange of knowledge and expertise.

Immediate effects of funding restrictions are that either ongoing cooperation collapses or future collaborations do not take shape. These impacts pertain especially to the university system, which experienced a more profound decrease in resource endowment than the extra-university public research sector. It is, in particular, one type of research collaboration that has been *vanishing, most conspicuously in the university system: research collaboration covered by core funding*. We have argued in the above that both core and project funding together

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[11] The BMBF project funding in nano S&T has increased since the mid 1990s now being approx. 100 m per year. At the same time, the 6th EU Framework Program is channeling about 1,400 m into this field between 2003–2006.

provide incentives to build up distinct research profiles and to seek extra-mural collaboration. Such a mix seems advantageous compared to either mere core or project funding. However, if core funding falls below a certain threshold, capacities for building and sustaining research profiles will decline significantly which, in turn, inhibits search for collaboration partners and benefits from collaborative activities. *Mid-term effects* are, for instance, *status hierarchies* emerging between the university and the extra-university sector. Table 1 shows that in 2003 MPG institutes have a budget/personnel ratio of 0.254, while the universities have a ratio of merely 0.101. According to this simple coefficient, Max Planck researchers are about 2.5 times better equipped than their colleagues at universities. This is consistent with our interview results that university researchers increasingly experience problems catching up with the instrumentation and research equipment of MPG institutes and, thus, fall short of such research partners.[12]

However, apart from budget cuts, accompanying regulatory structures also have adverse effects. First, research careers have become increasingly unattractive: not only have real income opportunities for younger researchers been leveled down, but *current changes in labor law have, in fact, erected new barriers to job mobility* because researchers face real income (or pension scheme) losses when moving from one type of institution to another. Second, *budget cuts have been accompanied by New Public Management (NPM) reforms* that exchange academic for hierarchical self-government and expand external control (de Boer et al. 2007). In his analysis of such NPM reforms in the United Kingdom, Georghiou (2001: 294) argues that public research sector institutions have been converging in their research activities and profiles, thus narrowing the capabilities of the research system as a whole.

8. Conclusion and discussion

Our analysis started with two observations: first, the German research system is highly differentiated and has tended towards institutional segmentation over the last two decades. Second, in a young and highly dynamic field, many research breakthroughs are stimulated at the intersection of established scientific disciplines and across fundamental and applied technological research. There is a tension between the need for effective inter-institutional collaboration on the one hand and the governance structures in the public research sector on the other hand. The article presented preliminary results of ongoing research on *collaborations between heterogeneous research institutions* in the German research system, particularly in the field of nano S&T.

We found that heterogeneous research cooperation across different institutions and organizations in the German research system (mainly universities, MPG

[12] Note that the teaching component of the university sector is leveled out in this comparison, because personnel and budget figures include both research and teaching (Table 1).

institutes, Helmholtz centers, FhG institutes) is a relevant characteristic of emerging fields like nano S&T. Furthermore, we identified various rationales for inter-institutional collaboration that seem relevant for scientists from diverse institutional backgrounds in their day-to-day work. By applying a “governance cube” of three major institutional characteristics at the “meso-level” of research (thematic interdependence; organizational dimension; resource endowment), we identified a number of institutional factors that seem conducive to research cooperation in nano S&T (such as the existence of distinct research profiles of partners; support for job mobility; research leadership; effective administration; sufficient core funding; and flexible mechanisms for resource allocation). But we also found that *by far not all opportunities for heterogeneous research collaboration are being utilized*. Hampering factors include stereotypes and prejudices; incompatible working routines; insufficient interface management; and budget cuts that limit the possibilities of establishing effective inter-institutional collaboration. Both public research policy and the management of major research organizations might have reason to reconsider the respective meso-governance and incentive systems in these regards.

Further research is needed to understand the institutional change that the German research system has been undergoing since the early 1990s, particularly with respect to highly dynamic fields such as nano S&T. Currently, we are studying the internal governance structures of the Max Planck Society (MPG), the Fraunhofer Society (FhG) and the Helmholtz Association of German Research Centers (HGF) in more detail, in order to further validate and expand our preliminary conclusions, particularly with respect to the changes indicated in Figure 1. Another dimension of our future research will include the governance of international collaboration of German research groups. In dynamic fields like nano S&T research, collaboration across national borders has considerably increased over the last two decades.[13] Hence, a central question is how international collaboration in fields such as nano S&T can be understood from a meso-level institutional perspective including various organizational cultures, funding systems, intellectual property rights regulations, career paths, or promotion criteria.

[13] An important aspect of this development is the growing relevance of the EU in funding research and the gradual emergence of what has been called the European Research Area (Kuhlmann 2001; Edler and Kuhlmann 2005).

References

Beaver, D.d., 2001: Reflections on Scientific Collaboration, (and its Study). Past, Present and Future, in: Scientometrics 52(3), 365-377.

Benz, A., 2007: Governance in Connected Arenas. Political Science Analysis of Coordination and Control in Complex Rule Systems, Chapter A Ia in this volume.

BMBF (ed.), 2005: Bundesbericht Forschung 2004, Bonn, Bundesministerium für Bildung und Forschung.

de Boer, H. / J. Enders / U. Schimank, 2007: On the Way towards New Public Management? The Governance of University Systems in England, the Netherlands, Austria and Germany, Chapter B I in this volume.

Bordons, M. / I. Gómez, 2000: Collaboration Networks in Science, in: Cronin, B. / H.B. Atkins (eds.), The Web of Knowledge, New Jersey, ASIS, 197–213.

Edler, J. / S. Kuhlmann, 2005: Towards One System? The European Research Area Initiative, the Integration of Research Systems and the Changing Leeway of National Policies, in: Technikfolgenabschätzung. Theorie und Praxis 14(1), 59-68.

Eurostat (ed.) 2003: Statistiken über Wissenschaft und Technologie. Daten 1991-2001, Luxembourg, Amt für amtliche Veröffentlichungen der Europäischen Gemeinschaften.

Georghiou, L. 2001: The United Kingdom National System of Research, Technology and Innovation, in: Larédo, P. / P. Mustar (eds.), Research and Innovation Policies in the New Global Economy. An International Comparative Analysis, Cheltenham, Edward Elgar, 253-296.

Glänzel, W., 2001: National Characteristics in International Scientific Co-authorship Relations, in: Scientometrics 51, 69-115.

Glänzel, W. / A. Schubert, 2004: Analysing Scientific Networks Through Co-Authorship, in: Moed, H.F. / W. Glänzel / U. Schmoch (eds.), Handbook of Quantitative Science and Technology Studies, 257-276.

Greve, R., 2005: Development of coordinated programmes of the DFG, in: Plattform Forschungs- und Technologieevaluierung (September 2005), 12-21.

Gruss, P., 2004: Grundlagenforschung als Basis für Innovation, in: MPG (ed.), Jahrbuch 2002, München, Generalverwaltung der MPG, 9-21.

Heinze, T., 2004: Nanoscience and Nanotechnology in Europe. Analysis of Publications and Patent Applications including Comparisons with the United States, in: Nanotechnology Law & Business 1(4), 427-447.

Heinze, T. 2005: Wissensbasierte Technologien, Organisationen und Netzwerke. Eine Untersuchung der Kopplung von Wissenschaft und Wirtschaft, in: Zeitschrift für Soziologie 34(1), 62-80.

Heinze, T., 2006: Kopplung von Wissenschaft und Wirtschaft. Das Beispiel der Nanotechnologie, Frankfurt / New York, Campus.

HGF (ed.), 2004: Programme - Fakten - Zahlen, Bonn, Helmholtz-Gemeinschaft.

Hohn, H.-W., 1998: Kognitive Strukturen und Steuerungsprobleme der Forschung. Kernphysik und Informatik im Vergleich, Frankfurt, Campus.

Hohn, H.-W., 2005: Institutionelle Grenzen der Modernisierung des deutschen Forschungssystems, in: Fisch, R. / S. Koch (eds.), Neue Steuerungsmodelle für Bildung und Wissenschaft. Schule - Hochschule – Forschung, Bonn, Lemmens, 161-174.

Hohn, H.-W. / U. Schimank, 1990: Konflikte und Gleichgewichte im Forschungssystem. Akteurkonstellationen und Entwicklungspfade in der staatlich finanzierten außeruniversitären Forschung, Frankfurt, Campus.

Hollingsworth, R. / R. Boyer, 1997: Contemporary capitalism. The embeddedness of institutions, Cambridge, Cambridge University Press.

Hullmann, A. / M. Meyer, 2003: Publications and Patents in Nanotechnology. An Overview of Previous Studies and the State of the Art, in: Scientometrics 58(3), 507-527.

Internationale Kommission, 1999: Forschungsförderung in Deutschland. Bericht der internationalen Kommission zur Systemevaluation der Deutschen Forschungsgemeinschaft und der Max-Planck-Gesellschaft, Hannover, Volkswagen-Stiftung.

Katz, S.J. / B.R. Martin, 1997: What is Research Collaboration? in: Research Policy 26, 1-18.

Kuhlmann, S., 2001: Future Governance of Innovation Policy in Europe – Three Scenarios, in: Research Policy 30, 953-976.

Laudel, G., 1999: Interdisziplinäre Forschungskooperation. Erfolgsbedingungen der Institution “Sonderforschungsbereich”, Berlin, edition sigma.

Laudel, G., 2002: What do we Measure by Co-authorships? in: Research Evaluation 11(1), 3-15.

Luhmann, N., 1991: Die Weltgesellschaft, in: ibid (ed.), Soziologische Aufklärung 2, Opladen, Westdeutscher Verlag, 51-71.

Melin, G. / O. Persson, 1996: Studying Research Collaboration Using Co-authorships, in: Scientometrics 36, 363-377.

Meyer-Krahmer F. / U. Schmoch, 1998: Science-based Technologies. University-industry Interaction in Four Fields, in: Research Policy 27, 835-851.

Moed, H. F. et al., 2004: Handbook of Quantitative Science and Technology Research. The Use of Publication and Patent Statistics in Studies of S & T Systems, Dordrecht, Kluwer.

Newman, M.E.J., 2004: Who is the Best Connected Scientist? A Study of Scientific Co-authorship Networks, in: Ben-Naim, E. / H. Frauenfelder / Z. Toroczkai (eds.), Complex Networks, Berlin, Springer, 337-370.

Nowotny, H. et al., 2001: Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty, Cambridge, Polity Press.

Röbbecke, M. / D. Simon / M. Lengwiler / C. Kraetsch, 2004: Inter-Disziplinieren. Erfolgsbedingungen von Forschungskooperationen, Berlin, edition sigma.

Schmoch, U., 2003: Hochschulforschung und Industrieforschung. Perspektiven der Interaktion, Frankfurt am Main, Campus.

Whitley, R., 2000: The Intellectual and Social Organization of the Sciences, Oxford, Oxford University Press, 2nd edition.