Chapter 5
Policy Networks and Change: The Case of High-T_c Superconductors

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1 The Discovery of High-T_c Superconductors

In September 1986 two European physicists from the Zurich Lab of IBM published a paper in the German *Zeitschrift für Physik* on "Possible High-T_c Superconductivity" in a ceramic material. Superconductivity is the phenomenon, first discovered in 1911, that certain pure metals and alloys lose their electrical resistance when they are cooled beneath a certain temperature, the "critical temperature" T_c. Superconductivity is conditional on very low temperature near absolute zero. It requires complex cryocooling technologies and expensive liquid helium as a cooling medium. Despite hard efforts to raise the critical temperature from these very low temperatures, no progress had been made since 1973, when niobium germanium with the T_c of 23 Kelvin, i.e. 23 degrees above absolute zero, was discovered. There were even theories predicting that superconductivity above 30 K was impossible. Again and again different physicists claimed to have found high-T_c superconductivity (HTS), but all the sensational reports turned out to be false. Now Müller and Bednorz claimed to have discovered an oxidic material, LaBaCuO (lanthanum-barium-copper oxide) with a T_c of 30 K. By December 1986 their experiments were replicated by two groups in Japan and the US. Soon it became clear that the so-called "Zurich oxides" were no exception - there were other oxidic superconductors with even higher critical temperatures. In January 1987, the US group succeeded in preparing a material which soon dominated HTS research: YBaCuO (yttrium-barium-copper oxide). It allows cooling with simple technologies and cheap liquid nitrogen.

With the discovery of YBaCuO, announced in a press conference (even before publication of the scientific paper) in mid-February 1987, a worldwide race in the science and technology of HTS was set off. Feverish activity dominated not only the scientific frontier, but also politics. As early as February 1987 governmental agencies in Japan started funding and organizing the field. Japan declared HTS a basic future technology and part of the MITI-Program "Technologies for the Next Generations' Industries".

Parallel to these Japanese activities, American congressmen started a campaign to commercialize superconductivity. America feared that they might win again in science while losing in the technological competition with Japan. The superconductivity campaign finally culminated in July 1987 in President Reagan's "Superconductivity Initiative", one point of which was to restrict the flow of information from American National Labs to foreign scientists.

The discovery of HTS triggered huge activities in science, industry, and science and technology policy. A very small scientific and technical field (in 1986) suddenly grew by a factor of ten and even more. This particular event offered researchers of science & technology the unique chance to study how a developing field gets organized, which actors use which strategies in policy formation, whether and how this is dependent on their previous position in the field and on special scientific and technological trends.

This chapter provides an analysis of the German HTS policy. It is based on both secondary data on public funding for superconductivity research before and after HTS, and on structured, open-ended interviews with HTS researchers from ten research groups at universities, research institutes and industry, with representatives of the main funding agencies and with members of an advisory committee established by the Bundesministerium für Forschung und Technologie (BMFT = Federal Ministry of Research and Technology).[1] The goal is to explain the formation of

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[1] The interview data were collected during summer 1988 (research groups) and winter 1988/89 (funding agencies, committee) in a project at the Max-Planck-Institut für Gesellschaftsforschung in Cologne in collaboration with the Institut für Wissenschaftstheorie und -forschung in Vienna, which will analyze these data along with data on Austria and Switzerland under a comparative perspective. A research report on the German case is forthcoming (Jansen 1991). Previous versions of this chapter were presented at the policy networks conference and at the ECPR Joint Sessions of Workshops, held at the Ruhr-Universität Bochum, 2-7 April 1990. The chapter benefited from the discussions at the conferences and with colleagues at the institute. I would like to mention Jürgen Häusler, Renate Mayntz, Andreas Ryll, Uwe Schimank and Raymund Werle for valuable discussions and comments. For technical assistance, I would like to thank Marie Haltod-Hilgers,

the HTS policy by showing the points of intersection between scientific and technological opportunity structures and between the relevant actors' different policy strategies.

2 An Outline of the General Approach: Policy Networks and their Adaption to Change

Since the seventies political scientists have been departing more and more from the traditional view of the state as a planning and regulating authority, implementing political decisions that were taken by parliaments. The end of the planning euphoria resulted in research into implementation devoted to finding out why policy programs did not work as they were intended to. Societal actors that possessed information and resources that the state was lacking were detected. A closer look at the implementation process even made clear that the distinction between policy implementation and the definition of policy goals and programs is often artificial. Blurring boundaries between public and private were observed. The top-down approach of traditional implementation research was questioned. "Implementation structures before implementation" were discovered that created policy issues and played an important role in policy formation. As a consequence the interest of policy analysts turned away from state regulation and hierarchical control towards forms of interest mediation, bargaining and collective decision making, towards the role of the state as a participant in these processes or as a designer of institutional arrangements, and towards the question of how these processes and institutional designs are related to the achievement of public goals. On the national level concepts like corporatism and private interest government emerged, on the level of sectors or sub-sectors concepts like meso-corporatism, policy community and policy network came up.

In the area of science and technology policy the problems of the attempt to use science for societal ends ("Finalisierung der Wissenschaft") are well known. The discussions on autonomy versus guidance of science have provoked endless debates (Polanyi 1951, 1968; Bernal 1970; Luhmann 1968; Böhme et al. 1972, 1973; Daele et al. 1975, 1977, 1979;

Cynthia Lehmann and Günter Schröder. The remaining faults are of course the author's, who alone rests responsible for the content of the chapter.

Küppers et al. 1978; Krohn et al. 1987; Keck 1984; Schimank 1988). Scientists are committed to defending the autonomy of science. Research institutes again and again exhibit the tendency to escape state guidance and to define their work on their own. The typical problems of top-down implementation are especially virulent in science and technology. Scientists are the only ones who have access to crucial information for the evaluation of their work. This gives them large discretion in defining their tasks according to their interests and equipment. They tend to define their objectives in intra-scientific terms since this is often the only way of structuring the task that is available. Basic science in particular is characterized by fundamental uncertainties on promising research directions and methods that cannot be overcome by project descriptions and policy goals.

What actually happens in science and technology policy is that goals and programs are negotiated and finally set up in a concerted process between science, industry and politics. Wittrock, Lindström and Zetterberg in their analysis of energy research policy have coined the word of implementations structures before implementation proper, which "exist in the sense of informal networks of interested parties before implementation" and "might well be active in defining and forming a program that will later reach the implementation stage" (Wittrock et al. 1982: 133). Another concept is that of "technical systems" (Figure 1) introduced by Shrum, which he defines as "centrally-administered networks of actors oriented to the solution of sets of related technological problems. They are characterized by relatively large size, cognitive complexity, sectoral diversity, occupational pluralism, and formal organization" (Shrum 1984: 63). Arguing against a superficial autonomy of science Shrum and his colleagues see technical systems as initiated and administered by the state with the aim of solving broad technical problems of social concern (Shrum et al. 1985: 47).[2]

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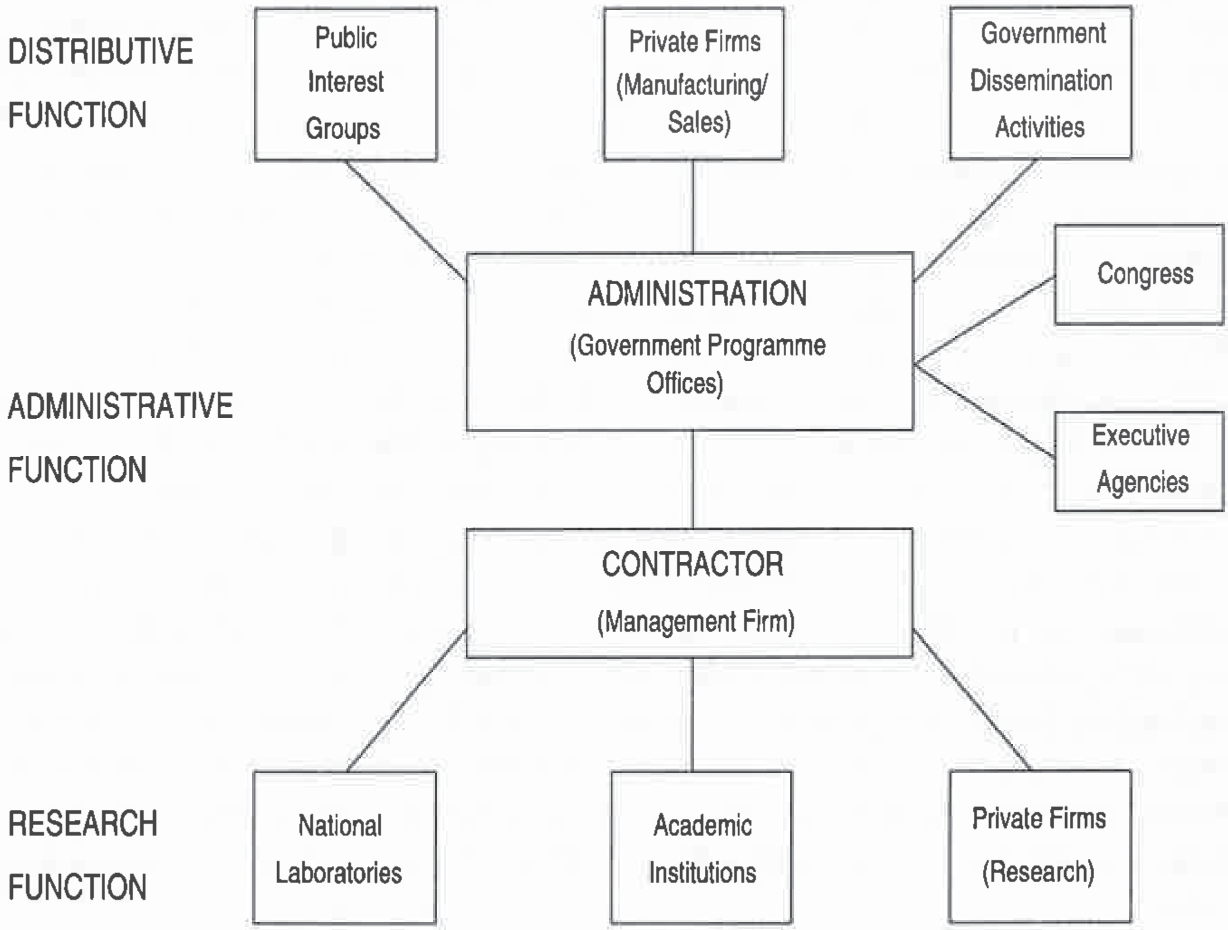
[2] See the differentiation between the competitive modality of network formation and the cooperative mode by Laumann et al. (1978: 466ff.). While the relations between the corporate actors in the competitive mode are basically antagonistic and linkages are based on resource dependencies, the implicit philosophy in the cooperative modes of network formation is the attainment of a collective purpose, for which the interorganizational field has responsibility, by conscious cooperation of various organizations. Especially the case of "mandated cooperation" seems to respond to the "technical system" concept of Shrum, in which governmental organizations are central control agencies.

Figure 1: Ideal Type Technical System



Source: Shrum 1984: 83.

I will use the concept of a policy network as a tool for the analysis of the relationship between interests and governmental departments/ agencies in the process of policy formation in the case of HTS. Kenis and Schneider suggest the definition, "A policy network is described by its actors, their linkages and by its boundary. It includes a relatively stable set of mainly public and private corporate *actors*. The *linkages* between the actors serve as communication channels and for the exchange of information, expertise, trust and other policy resources. The *boundary* of a given policy network is not primarily determined by formal institutions but results from a process of mutual recognition dependent on functional relevance and structural embeddedness." (Kenis/ Schneider, this volume above).

Compared to other policy process concepts like corporatism, meso-corporatism, negotiated economy, iron triangle, pluralism, policy community, issue network, policy universe etc. that are crowding the literature, the policy network has the advantage of being rather neutral. It can be used to denote several kinds of functions of the network (the pluralism/ corporatism debate, lobbying vs. participation in policy formation and implementation) and different levels of analysis (macro, meso and micro). Varying numbers, types and mixes of actors (individual firms/organizations vs. interest groups/associations vs. chambers with compulsory membership/representational monopoly; mixes ranging from only public [= intergovernmental networks, statism] to public and private actors and, finally, to only private actors [= private interest government]) can be considered. Networks can be characterized by varying degrees of conflict/competition and consensus/cooperation between the actors, by the degree of state domination or interest domination, of formalization/institutionalization and by the degree of closure of the network (pluralism/open access vs. elitism/closure).[3] While Kenis and Schneider seem to exclude individual actors from participation in policy networks, I would like to include them. In sectors which lack a high degree of "corporatization" and where personal expertise and reputation is important, like in science, the question of corporate versus individual actor has to be treated as an empirical one.

One of the problems of policy networks that is widely discussed is their resistance or adaption to change. Numerous policy studies show how established networks try to defend the status quo and fail to cope with external, mainly economic changes (see Midttun 1988a on heavy industry and Grant 1985, 1987, 1990, Farago 1985 and Waarden 1985 on agricultural policies). Within an established network regularly a special definition of the problems and issues involved emerges. Networks become cohesive and tend to have a definite view about what and who belongs to their field. New issues and actors are likely to face resistance

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[3] For a more encompassing discussion of the dimensions of policy networks and a location of some of the more common concepts into a typology using number and type of actors, function of the network and the power relation between state and interests see Waarden (1990: 5ff.). For a discussion of the use of the concept in the British literature, see Marsh/ Rhodes (1990).

and exclusion from the network. This problem of adaption, of inclusion or exclusion of new issues and actors is especially relevant in the case of research and technology policy, which typically has to react to the discoveries of basic science providing new knowledge. The explicit goal of policy programs in this area is to scan scientific developments for potential applications. The very quick exploitation of new opportunities is crucial for international competitiveness in high-tech fields which are characterized by cumulativeness, steep learning curves (Dosi 1982: 154; 1984: 86ff.) and first mover advantages (Williamson 1975: 34f.). Any inertia of networks in research and technology policy to respond to new opportunities created by scientific and technological breakthroughs thus poses serious problems.

My chapter will deal with the question of how the German superconductivity policy network reacted to the sudden breakthrough in superconductivity research. It shows first why and how the established network included the new issue - ceramic high-T_c superconductors - in its agenda in a very specific way that is determined by the existing network structure and resources. And it shows secondly why and how an actor from outside tried to enter the network, why it succeeded and how it shaped the structure and policy of the transformed network. The analysis deals with the transformation of the whole policy network and the formation of an HTS policy program as a consequence of the intersection of actor strategies and new opportunity structures[4] that are offered by scientific and technological change.

For the formation of the superconductivity policy I take as explanatory variables (1) the structure of the old superconductivity policy network, (2) the opportunities opened up by scientific and technological change (see section 3), and (3) the intentions and resources of the actors involved. To begin with, the set of actors is defined by the old network. New actors can enter the scene in accordance to the scientific and technological opportunity structure. With respect to the actors, I distinguish between three types: scientists interested in working on scientifically rewarding problems and in raising funds for their research, industrial

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[4] My use of the term "opportunity structure" departs from the use of Laumann et al. (1978: 471), who define an opportunity structure as a subnetwork within which exchange relations tend to be confined for several reasons. I use the term to denote the structure of opportunities which are exogenous to the network and are brought about by scientific, technological and market changes.

R&D (Research & Development) managers interested in defending old markets and developing new high-tech products and, finally, between them I see the state and its science and technology agencies, interested in guiding scientists to technologically relevant basic research, in organizing effective technology transfer from science to industry and in guaranteeing the competitiveness of the national industry.

3 HTS: Changes in Scientific and Technological Paradigms

Scientific paradigms (Kuhn 1962) form a frame of reference that guides researchers on their way to promising research questions and research objects. "Normal science consists in the actualization of that promise, an actualization achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of match between those facts and the paradigm's predictions, and by further articulation of the paradigm itself" (Kuhn 1962: 24).

Before HTS was discovered, superconductivity research was a declining field in science. The golden era of superconductivity in the sixties and seventies was over. Scientists turned to more promising fields, especially to semiconductor physics. Normal science in superconductivity was guided by the "BCS theory", developed in 1957 by Bardeen, Cooper and Schrieffer (and named after their initials), who were awarded the Nobel prize in 1972. Since the sixties, normal science consisted in proving the special mechanism of superconductivity, the "electron-phonon interaction" in various uncommon superconductors. Numerous competing explanations of superconductivity were almost all ruled out by experimental evidence in the course of "normal" superconductivity science. The search for superconductors with higher critical temperatures had been frustrated since 1973 when niobium-germanium with $T_c = 23$ K was found. The established electron-phonon mechanism even explained why all the attempts to discover superconductors with higher critical temperatures were in vain. The theory was thought to imply that superconductivity above 30 K was impossible. The only puzzle for the BCS approach was the superconductivity of "heavy fermions"[5] discovered in the seventies, which did not seem to match up with the predictions.

The appearance of HTS fundamentally challenged the BCS theory and changed the course of superconductivity research. Experimental evidence on a traditional key experiment (isotope effect) processed with the new material is inconclusive. Until now no one has succeeded in designing a crucial experiment confirming or ruling out BCS theory. It is far from clear whether superconductivity in HTS is based on the traditional mechanism. Many alternative theories have appeared on the scene.

HTS not only opened up new scientific frontiers for physicists - experimental and theoretical - but also caught the interest of other natural sciences, namely of chemistry and material science. The race for the discovery of room-temperature superconductors was on, the dogmatic limit of 30 K had been overrun. Chemists and material scientists were highly motivated, because the winners would be sure to reap great scientific (and economic) rewards. Other disciplines with different conceptualizations of superconductivity got involved; a chemical theory of HTS, for instance, was proposed (cf. Simon 1987). Soon it became obvious that the complex chemical structure and the ceramic nature of the new materials made an interdisciplinary approach of physicists, chemists and material scientists necessary, not only in applied science but also in basic science. The ongoing race for new materials implies that only those physicists who collaborate with the best preparative groups will have the finest samples of materials and will have them in time. On the other hand, only those preparative groups that collaborate with the best measurement groups with arcane know-how and equipment will get their samples characterized in every respect. This will guide them in their search for new materials or material improvement. These are strong intrascientific incentives for the various disciplines to cooperate.

Another important feature of HTS research compared to traditional superconductivity research is the closeness of basic and applied research. While the heavy fermions - in the center of basic research in 1986 - were technologically absolutely irrelevant, any know-how on HTS materials is of direct technological value. Work in basic and applied research

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[5] Heavy fermions are f-electrons which have effective masses up to 10^2 times greater than normal electrons. Some of the materials containing heavy fermions are superconducting. The micromechanism for the superconductivity of heavy fermions is considered to be spin-fluctuations (Fachlexikon ABC Physik 1989).

often only differs in perspectives and conclusions but not in the actual approach. For instance, thin films are necessary for many basic physical experiments, but they are also the fundamental base of HTS electronics.[6]

In summary, the change in the scientific paradigm of superconductivity can be shown in three dimensions:

- the challenge of the physical theory of superconductivity,
- the incorporation of other natural sciences into the field with different theoretical concepts, different know-how and equipment,
- the jump of basic research close to technological exploitation.

The change of direction in basic research also caused a change in the technological paradigm of superconductors. The term "technological paradigm" was coined by Dosi (1982) in analogy to the definition of a scientific paradigm. "We shall define a 'technological paradigm' as a 'model' and a 'pattern' of solution of 'selected' technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies. ... In other words a technological paradigm (or research program) embodies strong prescriptions on the *directions* of technical change to pursue and those to neglect" (Dosi 1982: 152).

Within superconductivity, technological research had been restricted to metallic alloys, and the methods employed had been metallurgical ones. Researchers had almost given up searching for materials with higher critical temperatures, and engineers had resigned themselves to the ongoing struggle with the very low temperatures and the complicated helium infrastructure required when working with low-temperature superconductors. Applications in electric power (superconducting cable, superconducting switches, transformers, energy storage) turned out to be feasible but not competitive. In the seventies the German project to develop a superconducting magnetic train was abandoned in favor of a different system. Superconducting magnets were only used where extraordinary power was necessary and costs were secondary as in magnet technology for the fusion project developed at the Kernforschungszentrum Karlsruhe

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[6] This is illustrated by the following example. To perform the "tunnel experiment", which is essential for explaining the micromechanism of HTS, one must have a "tunnel element". This is made up of a sandwich of a substrate, a thin superconducting film, a very thin insulating film and another superconducting film. Under certain conditions, the electron pairs in the superconductor can "tunnel" their way under the insulator. This tunnel element, vital to basic HTS research, serves at the same time as a magnetic sensor or a switching device in applied research.

(KFK, a national research lab) or in magnet technology for high-energy accelerators. In the eighties, to everyone's surprise, magnetic resonance imaging (MRI) magnets used in medical diagnosis turned out to be the first respectable market for superconducting equipment.[7] Besides applications in electric power since the seventies, there were efforts to use the "Josephson Effects"[8] of superconductors. Josephson junctions can be used as very fast switching devices with almost no power dissipation or as hypersensitive detectors of magnetic fields, for instance, in medical diagnosis. While the application efforts of superconductors in electronics did not succeed - IBM gave up the Josephson computer project in 1983 work on superconducting sensor technology was still going on. Estimates of the world market for superconductor equipment before HTS are around DM 500 million annually, more than half of this being devoted to medical application in MRI tomography (magnetic resonance imaging). The industry involved belongs to the electrical and the electronics sector. In Germany the main directions of research in 1986 were the improvement of existing superconducting materials (niobium-tin, niobium-aluminum), new applications in the sensor technology, new cooling concepts, magnet technology, application in magnetic-resonance-imaging devices for medical diagnosis and the construction of a superconducting electrical power generator.

The arrival of ceramic high-T_c superconductors not only brought back into consideration long-abandoned projects such as superconducting power transmission, superconducting trains, superconducting supercomputers. It also opened up new opportunities, for instance, in high frequency applications, sensor technologies, cooling technologies. Market estimates for the year 2000 range between DM 3 billion and DM 75 billion.

What is more far-reaching is that ceramic materials require special chemical preparative know-how and processing techniques which are available not in the electrical and electronics industry, which used to work on superconductors, but in the chemical industry. The chemical industry also has a long tradition in the search for new technologically relevant materials (and is eager to be the first to patent them).

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[7] Siemens, which has been working on superconductivity technology since the sixties, was able to take up this opportunity very quickly and for a long time was the market leader in magnetic body scanners.

[8] Brian Josephson who predicted these effects was awarded the Nobel prize in 1973.

To sum up, the change of the technological paradigm concerns the material aspect of superconductors as well as the application aspect of superconductors:

- New and completely different materials open up the patent race for higher T_cs and even for room-temperature superconductors.
- New and completely different materials require different preparative and processing technologies.
- The high-T_c superconductors - and, to an even greater extent, potential room-temperature superconductors, provided they meet technical requirements - will make many old application ideas for superconductors profitable, mainly in the area of power engineering.
- High-T_c superconductors - and, to an even greater extent, potential room-temperature superconductors, provided they meet technical requirements - will open up new opportunities, mainly in the area of electronics/sensor techniques.

These changes in the technological trajectory of superconductors bring about several consequences:

- The market for existing superconducting equipment is challenged.
- The market for power engineering is challenged by the threat of potential substitution by superconducting equipment.
- New market opportunities arise for electronic/sensor applications of HTS.
- New market prospects open up for providers of the best superconducting system (appropriable by patents or licenses) and for providers of preparative and processing technologies making the "system" a useful material.

So, HTS technology crisscrosses the conventional sector structure of industry. The turn to ceramic materials challenges the old superconductor industry and gives an opportunity to sectors with ceramic know-how and production facilities to find their way into superconductors.[9]

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[9] See for instance Jaffe (1989), who analyzes the technological position of firms within the traditional sector structure of industries and who links them to R&D successes.

4 Identification of the Superconductivity Policy Network

The reconstruction of the existing superconductivity policy network can begin with an analysis of research funding in the area of superconductivity in Germany in 1986.

Superconductivity funding in Germany is dominated by BMFT-financed programs in 1986. The Bundesministerium für Forschung und Technologie (BMFT = Federal Ministry of Research and Technology) is the central state actor in the field of science and technology in Germany. Mission-oriented research (Fachprogramme of the BMFT), such as research on nuclear and alternative energy, space research, medical research and also technologically oriented research, belongs to the domain of the BMFT. It is conducted either at universities, industrial labs or non-university research institutes including the "Großforschungseinrichtungen" (= GFE, big science centers, comparable to national laboratories in the US). While universities, industry and research institutes get special grants from the BMFT earmarked for certain projects, the thirteen Großforschungseinrichtungen are institutionally funded.

There are four BMFT programs dealing with superconductivity, one science-oriented "Basic Research Using Large Equipment", and three programs on market-oriented research. The latter make for more than two thirds of the total funding budget in 1986. These are programs for the development of superconducting MRI devices in the medical field, for the development of a superconducting power generator and the more basic program on superconductivity technology within the scope of the special program "Physical Technologies".

Since the task of funding HTS research later was assigned to the latter program, a closer look at it may be worth while. After the change in government the general strategy of the BMFT in direct project funding of market-oriented science and technology research was the concentration of efforts on basic research in key technologies like information technology, material research, biotechnology and physical technologies, that might generate large positive external effects legitimizing state intervention.[10] The funding concept was redesigned as to incorporate and concentrate on basic research and to bring together science and industry

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[10] In general, direct funding was decreased while indirect means of R&D subsidies were intensified in the course of deregulation. Budgets for direct funding of industrial projects have been cut down by DM 1 billion since 1982.

in so-called joint research projects (Verbundforschung). "Verbundforschung" is intended to address problems in R&D too large for one firm, institute or university alone. In a joint project two or more firms and several academic researchers are to work together in precompetitive research on the principle of division of labor. Thus, existing R&D resources can be employed more efficiently, public funding can be concentrated on major projects, and structures promoting technology transfer can be built up (Mennicken 1988; BMFT 1987a: 53ff.; Kulina 1988; Chesnais 1988: 54). Funding for industry was deliberately intended to be subsidiary to industry's own efforts and to be degressive over time (see BMFT 1988b: 20).

The "Physical Technology" program in general and the superconductivity part in particular were lagging behind this general strategy of the BMFT. The program had the lowest rate of funding in the form of "Verbundforschung". In 1986 only 14.9% of the industry funding in this field was given in this form. By 1987 the rate increased to 31.6% still well below the mean of 56% for all market-oriented technology programs. 32 joint projects were in progress in 1987, in contrast to 96 individual research projects. Parallel with the increase of joint projects the share of funding for industry declined. In 1984 before the joint projects, industry got 67% of the budget; in 1987, the rate of funding for industry had declined to 52% with 32 joint projects.

The part of the program concerning superconductors was even more dominated by large firms from the electrical and electronics industry. Its share in the budget in 1984 was 84%. In 1984, the BMFT decided that the program's orientation was not clear enough and reorganized it. As a consequence, the participation of academia increased from 16% in 1984 to about a quarter in 1986, the year before HTS appeared. Joint projects did not play an important part in the program; there was only one joint research project out of 10 projects in 1986.

Besides the BMFT there are two science-oriented funding agencies involved in superconductivity research. The Volkswagen Foundation, a private foundation founded in 1961 by the Federal Republic and the state (Land) Lower Saxony, funded some projects on cryoelectronics in 1986, as part of their program "Microstructure technology", which was to be completed by 1988. The Deutsche Forschungsgemeinschaft (DFG) funded two special research areas (Sonderforschungsbereiche = SFB) in 1986. One of them was created especially for a research group studying heavy fermions, the other was to be finished in 1988. A new program was, of course, intended by that research group. These programs were devoted partly to superconductivity research and related phenomena. The DFG also funded very few individual research projects in the "Normalverfahren" (normal procedure), mainly theoretical work on heavy fermions. Unfortunately, figures on this kind of funding are not available. The following table gives an impression of the funding intensity of the six programs in 1986:

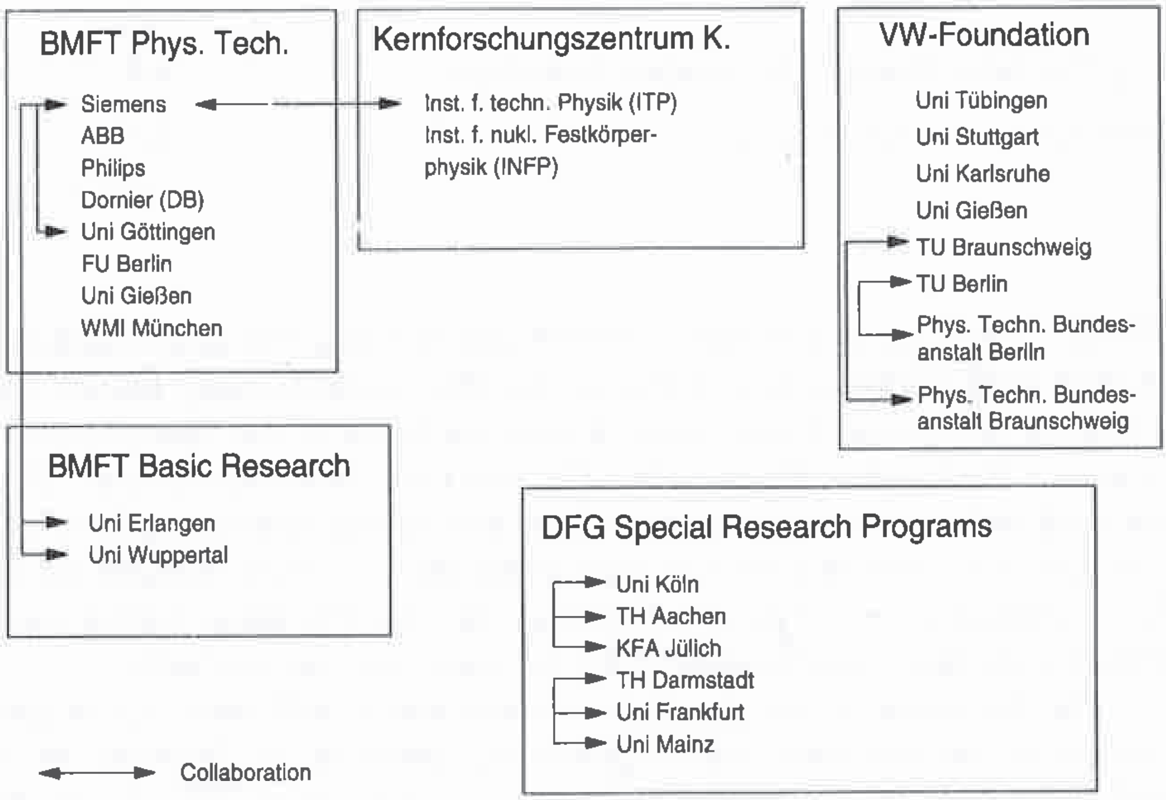
Table 1: Superconductivity Project Funding in Germany in 1986

	in million DM
BMFT Superconducting Medical Equipment	5.2
BMFT Superconducting Power Generator	3.3
BMFT Superconductivity in "Physical Technologies"	3.7
BMFT Basic Research Using Large Equipment	0.8
VW Foundation Program Microstructure Technologies	0.6
DFG Special Research Programs	3.6

These figures do not include institutional funding for superconductivity at the Großforschungseinrichtungen. In 1986 institutionally funded superconductivity research was done at two institutes of the Kernforschungszentrum Karlsruhe. The Institut für nukleare Festkörperphysik (INFP) focused on basic research on materials and the micromechanism of superconductivity. The Institut für technische Physik (ITP) worked on high-field materials and magnet technology for the European fusion project. Figures on their superconductivity budgets are not available.

On the basis of the funding information, I will now try to give a picture of the relevant superconductivity network in Germany in 1986 before HTS was discovered (Figure 2). The two BMFT programs devoted to prototype development in medical instruments and power generators were excluded since these programs could not react to HTS because of their advanced stage, and the four participating firms are or were involved in the basic program anyway. I regard funding, information exchange and explicit collaboration on research projects to be linkages between the corporate actors that participate in the remaining programs. I assume that actors within the same program have some information exchange as is indicated by the boxes around each program. This can be validated at least for the VW program, within which conferences for information exchange on cryoelectronics were held regularly, and for the BMFT program "Physical Technologies", where meetings of the project leaders were common, too. The arrows indicating collaboration within each box are confirmed by funding information, and those crossing the program boundaries are confirmed by interview information. Only one collaboration tie was mentioned in an interview (by Siemens to the University of Munich) which was not covered by the actor network derived from the funding information.

Figure 2: The German Superconductivity Network in 1986



The central actor is clearly Siemens. They collaborate with three universities as well as the more technologically oriented institute of the two at the KFK involved in superconductivity research.[11] All researchers collaborating with Siemens are funded by the BMFT, either by project funding or by institutional funding. Siemens is the only actor whose collaboration ties cross the program boundaries. All the other collaborations of academic actors stay within program boundaries.

5 The Policy Formation: Defining an HTS Funding Program

5.1 The Reaction of the Established Policy Network

In June 1987 - surely influenced by the superconductivity technology war between USA and Japan - the BMFT made up its mind to start a national research effort in HTS. They were extremely dependent on the evaluation of HTS by the leading scientists from academia. In January 1987 the program managing agency for the 'Physical Technologies' held one of the regular meetings of experts and project leaders in the superconductivity funding program. The ministry's and the agency's officials had already learnt about the breakthrough in superconductivity from newspaper articles. They wanted to get some evaluations from the scientists in order to decide about the future directions of the program. Contrary to their expectations, the scientists were very skeptical about high-T_c superconductivity. Obviously, nobody had yet succeeded in replicating the findings, but this was not admitted freely. Nobody was ready to change his research program and no one asked for special funds. This situation was to change soon. Exactly on the day of the meeting a group around Politis at the KFK succeeded in replicating the Müller/Bednorz results (Politis 1987: 121). This was the starting signal to the superconductivity community in Germany. Now they began to trust the sensational news from the US.[12] The KFK arranged a meeting of the German superconductivity researchers at the KFK on February 19, 1987, in order to evaluate the findings and to discuss organizational and research strategies. They did invite the BMFT to this meeting but turned

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[11] In the seventies the ITP was also funded by the program "Physical Technologies" for the development of cryogenic infrastructure.

[12] See Knorr-Cetina (1988) for an explanation of physical closeness and body-presence as factors in the creation of scientific belief and certainty.

to the department for 'Material Research' where they had personal contacts. The BMFT department 'Physical Technologies' was informed only at the very last minute.

Since participation in the first days of the superconductor race was not very expensive, no demands for large funding programs came up at the first meeting of about thirty scientists. Only the university researchers who were suffering from decreasing institutional budgets could not even afford to buy the chemicals needed, to telephone with overseas colleagues or to cover travel expenses. They asked for some seed money, and on the basis of the established program the BMFT was able to respond to these demands rather quickly. In April a small 300,000 DM special program on HTS was lanced, that distributed small amounts of money to 30 university institutes. Most importantly, the BMFT and especially the program managing agency, the "VDI-Technologiezentrum" (VDI-TZ = the Technology Center of the Association of German Engineers), acted as a mediator and information broker on the scene, organizing information letters and meetings, screening people and equipment and attending the European HTS conferences.

The BMFT's final decision on a larger HTS program was based on an intensive discussion of the technological potential of HTS and of German science and industry resources within the "implementation structure before implementation". An important date in this process that may have convinced the BMFT as well as the superconductor industry of the technological importance of HTS despite the basic science nature of this research was an IBM result showing that superconducting thin films were able to carry currents as high as 10^5 A/cm^2. This finding became known in the first days of May 1987. On May 8, 1987, the project managing agency and the KFK invited the whole superconductivity scene, including science, industry and politics, for a discussion aimed at establishing the important research questions and priorities. In June the minister himself met with leading scientists. They strongly urged for the extension of BMFT funding to basic science questions in HTS. Given the applied orientation of the research done at the labs of the traditional superconductor industry this meant funding of university research projects. In July the final version of the HTS program was checked in a meeting with leading experts from science and technology.

When it became clear that the BMFT was going to engage in the funding of basic university research in the case of HTS, the two science foundations deliberately decided to leave this field to the BMFT largely.

This was conditional on the very serious shortage of funding budgets in both foundations caused by the strong demand of the universities for project funding in the course of restrictions in the institutional budgets of the universities. They both followed a policy of keeping only a small but excellent part of their domain, namely two special research areas and a large interorganizational project on Josephson junctions.[13]

On July 23, 1987, the BMFT announced funding for application-oriented basic research in HTS. The funding condition was that local researchers from various university institutes and disciplines cooperate on a common research project. The announcement was clearly addressed to the universities, but industry was invited to participate under the condition that they would fund their own part of a joint project or would cover a substantial amount of the costs of the academic researchers.

Compared to the old superconductivity program this was a completely new approach, a definite turn to basic research, to university research and to interdisciplinary research. The BMFT plan in summer 1987 was about three to five years of funding of interdisciplinary basic research at universities and afterwards a long-term (7-10 years) phase of application-oriented industrial projects (BMFT 1987c).

The BMFT saw an opportunity of taking part in the international superconductor race successfully, since German academia and industry had a long tradition of superconductor research and technology. Faced with extreme international competition and protectionist measures even in the basic science stage, the BMFT realized it was necessary to intensify and coordinate a national basic research effort. The electrical industry of the old network was lacking experienced personnel for the handling of the new ceramic materials. This problem could be overcome by relying on university scientists which were able to take up the topic quickly and on a broad scale. There were strong intrascientific incentives for the collaboration between various disciplines.

The physicists of the old community managed to catch the interest of many colleagues from chemistry, crystallography, material science and engineering sciences who were ready to start an HTS project. By September 1987, a total of eleven university-centered research groups had formed. Fifteen institutes from the old network are non-industrial and

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[13] In 1990, the DFG again has lanced a program on the chemical edge of superconductivity research, a special research program on unusual valence states in solids (ungewöhnliche Valenzzustände in Festkörpern).

non-GFE research institutes: Almost two thirds of them became the cores of nine out of the eleven BMFT-funded groups, while another two have received grants for individual research projects. There are only two new groups (Saarbrücken and Regensburg) which are not based on an old network institute.

The engagement of the university scientists from the old network in the building of the joint projects was not only motivated by the funding opportunities offered by the HTS program. Another reason for their involvement was that HTS was a unique chance for them to establish the core of a material science institute at their university which for long had been prevented by faculty interests and the unwillingness of the faculties to give up any competencies. Such institutes were - this was their opinion - well suited for attracting funds of industrial corporations and state agencies in the future.

The BMFT and the program managing agency were well aware of the problems concerning interdisciplinary research in universities, so they gladly took the opportunity to establish interdisciplinary research projects at the universities without facing any resistance of the scientists. The foundation of a special HTS institute that might have provided the best conditions for interdisciplinary work was deliberately disregarded. It would have required a general political consent on the site and the design of the institute, as well as a search for adequate buildings, directors and researchers. All this was too time-consuming and - after all - too risky, since the technological future of HTS was far from being clear. Another reason for deciding against an institute may have been the consideration that once they get established, research institutes tend to define their research tasks rather autonomously while universities funded by earmarked money showed to be more responsive to the demands of application. This view was widely shared by the industry involved. What was needed was a quick and cheap solution that could be revised at a later stage. The best course of action was to take advantage of the existing infrastructure and personnel at the universities. For the university researchers a centralized approach would have created the situation of "the winner takes all". Thus, a decentralized program was better able to find their consent, too.

What remains to be explained is why the industry of the superconductivity policy network accepted the turn of the BMFT program towards university funding at the expense of the industry. In 1986 more than three-fourths of the program budget (DM 3.7 million) went to industry.

As HTS research began to expand in 1988, industry's share in the increased budget (DM 13.2 million actually spent in 1988) declined to 18%. Although this was still an increase in absolute terms, the firms could have been expected to object to their relative standing within the program, but they did not, and their response to the BMFT's offer to the industry to participate in the university projects was meager. Only one of the old network firms joined one of the eleven university joint projects that were founded in summer 1987. The large corporations decided to start own research groups relying on their established informal contacts to the university researchers of the old network. Why didn't they try to get public funding for their own research efforts? Why did they support the university-centered approach chosen by the BMFT? In my opinion there were several reasons:

- Industry as a collective actor was interested in building up an infrastructure for HTS research at the German universities.
- The industrial actors were aware of the relative advantage of interdisciplinary university research groups in the beginning of the superconductor race compared to their own research groups which were specialized for metallic superconductors and not for ceramic ones. They were interested in maintaining the national position in the international competition. This was possible only by giving public funds to the universities who could not work without such funding.
- The German electrical industry opted for a wait-and-see strategy in the beginning. They set up only small groups within the corporations leaving the first steps of research to the state-funded universities. They were prepared to start larger efforts if a technical breakthrough occurred, at which point they would be sure to get substantial public support (see the BMFT time schedule for HTS research in June 1987, BMFT 1987c).
- The industry, along with the whole superconductivity community, awaited a major increase in the public budgets for superconductivity research. This made the distribution of funding a non-zero-sum game. But this increase in funding was expected to be conditional on the quick formulation of a sound program. This put large pressure towards consent on the whole policy network.

5.2 The Challenge of the Established Superconductivity Network

The break in the scientific and technological paradigm of superconductivity challenged the established network to incorporate the chemical and material science questions posed by HTS. This problem was handled within the old network by relying on university researchers that established interdisciplinary university groups. But there were other answers to this problem. The break in the technological paradigm of superconductors offered new opportunities not only to university scientists possessing ceramic and chemical know-how, but also to chemical industry. Hoechst, a large German chemical firm, took up this chance and succeeded in entering the established network.

Hoechst is one of the three leading German chemical corporations which are known for their very high rate of self-financing of R&D (98%), as well as for their high rate of in-house basic research (6.3%, see Häusler 1989) and their good connections to the chemical departments of German universities (Rilling 1986; Grant et al. 1987; Krempel 1988).

In the eighties, world-wide competition and restricted resources forced high-technology firms to think about new research strategies. Even the largest corporations were no longer able to get along with internal R&D efforts alone (Fusfeld/ Haklisch 1985). The ability of any firm to build up the basis for innovation and economic growth on its own steadily decreased. Technological change shortened product cycles and thus the time available for amortization on R&D expenses. High-tech products and processes depended more and more on the combination of know-how and technologies from different fields. This made R&D more expensive and, what is more important, considerably decreased the likelihood of one company's possessing all the necessary know-how and equipment. High-tech corporations responded to these challenges in two ways:

- They strengthened the cooperation with external research institutes and universities, and
- they began to think about collective R&D, i.e. collaboration with competitors in precompetitive research (Fusfeld/ Haklisch 1985; Chesnais 1988; Hagedoorn 1989).

Hoechst was one of the first German high-tech corporations to draw conclusions from changing conditions for technical innovation. In 1981 Hoechst attracted the public's attention by deciding to finance a biochemical laboratory at Harvard University, and in 1985 it decided (along with other chemical companies) to participate in the long-term, basic-research-oriented BMFT programs on material research and on biotechnology. The material research program was the first major state-funded research in which the German chemical industry participated. It became the paradigm for the new concept of "Verbundforschung" (joint industrial research projects); it encompassed 120 joint projects by 1987 (compared to only 20 single research projects), more than in any other special program. The project managing agency is not the VDI-TZ responsible for superconductivity technology, but the Kernforschungsanlage Jülich (KFA), one of the big national labs of the BMFT. The industrial firms involved in the material research program are generally large chemical firms. Planned for ten years, the program's goal is to promote long-term, scientifically and economically risky research projects. The scientific and technical potential of German researchers within academia and within industry shall be focused on selected questions by means of joint projects.

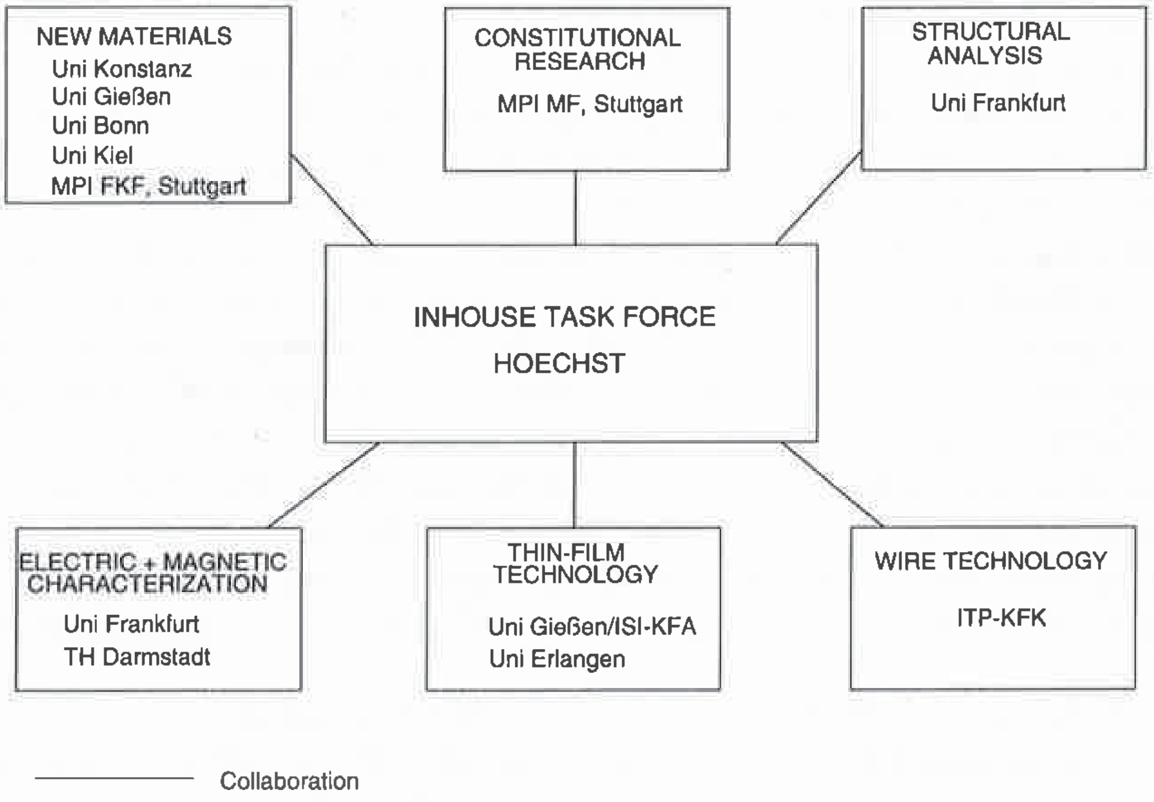
Probably due to the misrouted information within the BMFT - the department for material research was invited to the first meeting of scientists on HTS -, the R&D department of Hoechst found out about HTS and the meeting. Looking for new products and new markets, the R&D managers decided to attend the meeting as an information base. After the Karlsruhe meeting, the Hoechst R&D management decided to invest heavily in HTS research immediately. They saw HTS as a long-term material research project with considerable market potential. In the eyes of the managers the kind of approach that would be necessary to make high-T_c superconductors a technologically useful material fitted well together with the general concept of the material research program of the BMFT. In Germany, Hoechst had not only the greatest chemical expertise but also the best-suited equipment for developing the materials that could enter (and win!) the superconductor patent race. Aware of their competitive edge, they took immediate advantage of their inside information to secure themselves an excellent starting position.

Hoechst realized quickly that in order to participate in the worldwide patent race for HTS it needed to acquire knowledge about superconductivity in general and processing technologies, such as wire and thin-film fabrication, in particular. This clearly could not be done by an internal research group alone. In the very competitive patent race, it is especially crucial to have a variety of approaches, since no one can tell which approach will be successful in the end. At the same time, collaboration with competitors was impossible in the search for alternative superconductors. Too much was at stake.

Since knowledge about superconductivity was not available within the company, Hoechst managers could foresee that learning processes would require some time and external support. They decided to follow a strategic networking approach to the problem, which made Hoechst a factor that the BMFT and the old superconductor firms had to reckon with in the evolving HTS scene. Within two months after the Karlsruhe meeting they had an internal task force for HTS research made up of about six researchers from the ceramics department and from the department of technical physics. They augmented this in-house task force by making cooperation contracts with scientists from universities and research institutes as a strategy of minimizing risk, of getting access to knowledge and equipment and of recruiting experienced personnel. The criterion for choosing scientists as collaborators was expert know-how in either superconductivity, processing techniques or solid-state/structural chemistry which might provide clues for the search for new superconductors. By April 1987 the research management of Hoechst had concluded contracts with twelve scientists from outside in a concerted action with their patent department. HTS projects of collaborating scientists for about DM 9.2 million were planned. Hoechst partly followed the joint research model of collaboration between industry and science that had been established in the material research program. Obviously they were convinced that HTS would become a subject of this program soon. They deliberately departed from the joint research approach as far as collaboration with competitors in the material patent race was concerned. In spite of this violation of competitive neutrality, they presumed that their approach would be approved by the BMFT. They intended to provide part of the funding for the scientific research program and assumed that the BMFT would pay for the rest.

Figure 3, showing the Hoechst collaboration network, is reconstructed mainly according to interview information. While the scientists in the upper boxes of the network are new in superconductivity research - they are providing the chemical and ceramics know-how - all the scientists in the three lower boxes come from the old superconductivity network. Having managed to choose scientists from each program and even from the two Großforschungseinrichtungen that were involved, Hoechst has clearly succeeded in maximizing know-how and information flow. Surprisingly, there are two institutes among Hoechst's new collaborators, the University of Erlangen and ITP-KFK (the Institute for Technical Physics at the KFK), which collaborate with Siemens in conventional superconductivity research.

Figure 3: Superconductivity Network of Hoechst, April 1987



Hoechst was successful in taking advantage of the opportunity presented by the break in the technological trajectory of superconductors. Success in entering a new technological field depends on organizing quick access to knowledge and equipment, and success in the patent race is dependent on following a variety of different approaches while preventing competitors from doing the same. Collaboration with academic scientists was the fastest and easiest way for Hoechst to achieve these goals. They reacted to the challenge of HTS with the construction of a corporation-centered research network in both fields.

Within the BMFT, the department of Physical Technologies was able to establish its competencies for the new field of high-T_c superconductivity very quickly. Their budget for superconductivity research could easily be expanded to include HTS. Not later than in July 1987 the research management of Hoechst had to realize that HTS was not within the domain of the material research program but belonged to the program "Physical Technologies", which had not included the chemical industry up to that date. They realized that this program was dominated by electrical industry, namely by Siemens, and that material science questions were rather new. Joint research projects still were uncommon in this area. The BMFT's decision to concentrate funding on basic research in this context also meant the exclusion of industry from funding, at least in the field of material research. Nevertheless Hoechst insisted on the optimality of their industry-centered approach and tried to convince the BMFT that it was necessary for industry to include industrial joint projects on the material science questions from the beginning. For the established superconductivity policy network the solution to delegate the material science questions to university research groups was viable, but not for Hoechst. They tried to make clear that research on superconducting *materials* was their genuine domain. Hoechst was in an excellent position to bargain with the BMFT, having its own task force with fifteen scientists in contact with twelve elite academic institutes. The chemical firm reminded the BMFT of its general philosophy of industry-university cooperation and technology transfer, and warned that the ministry's failure to fund this extraordinary group would give the wrong signal politically.[14]

In September 1987 Hoechst took the initiative and applied for a grant for a joint Hoechst + collaborator research project, although the July announcement clearly did not include funding for industry. Just two weeks later, on September 23, 1987, the BMFT announced a second funding program for industrial joint projects on the technical potential of HTS. The design of the program followed the usual concept of joint projects, with two or more firms joining academic researchers for a common project, and industry receiving a maximum of 50% of their countable project costs and paying for 25% of the costs of their academic partners. So the BMFT formally adopted Hoechst's position and departed

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[14] Hoechst warned the ministry's officials that they were ready to complain about a failure to include an industrial material research project in the HTS program on the highest level. The fact that the minister of research and technology, Heinz Riesenhuber, belongs to the "family of chemists" - he has a doctoral degree in chemistry - probably played an important role in the considerations of both sides.

from its initial "university-funding-only" policy. It augmented the university-centered approach with an industry-oriented program.

6 The Transformation of the Policy Network: Compromise on the Funding Priorities and the Emergence of an HTS Industry Consortium

The BMFT department "Physical Technologies" had been forced by Hoechst to expand its funding to include an industry-oriented program, but the thrust of the strategy changed only slightly - from "universities only" to "universities first" - and the motivation remained the same. Basic research in a completely new field (ceramic superconductors as opposed to metallic ones) was needed, in which, from the point of view of the old superconductivity policy network, only the universities could provide expertise and people. Know-how not yet embodied in equipment was in the heads of experts who were not available in industrial labs at the beginning. Universities were leading in research in summer 1987 and needed public funding. Industry, especially the old superconductor industry, needed some time to adapt to the new situation, to recruit solid-state experts necessary for the new research questions. And the large corporations that were able to go into basic HTS research were strong enough from the BMFT's point of view to finance their research expenses without public subsidies.

The BMFT had managed to get DM 12 million extra for HTS research for 1988, supplementing the existing low-temperature superconductivity budget of DM 4 million. Further budget increases were not to come until 1989 and the following years. Refusing to split the 1988 budget between cheap university and expensive industry research, the BMFT decided that universities would come first. Although it formally announced an industry-funding program, no money was actually set aside for this program. In autumn 1987, the old superconductors industry sent their applications (abridged versions) to the BMFT. Among them were large projects by Siemens and by AEG, the second-largest electrical corporation in Germany now belonging to Daimler-Benz. All the industrial applications were simply postponed by the BMFT.[15] The old superconductor industry consented to this, but the chemical industry objected strongly. In December 1987, the BMFT set up an advisory committee on HTS as a conflict-managing strategy. Members of this committee came from industry (Siemens, AEG, Philips, Hoechst), from the two involved national labs (KFK and KFA) and from two of the universities of the old network (Karlsruhe and Darmstadt). Hoechst was the only newcomer in the committee and presumably took an isolated position. This committee was intended to work out recommendations for the HTS science and technology policy of the BMFT. It also served the BMFT as an information and coordination instrument for the developing HTS network, especially for industry and national labs which were not or not yet involved in BMFT projects. The committee also allowed the BMFT to gain consent for its strategy - members were deliberately selected not so much because of expert know-how but because of position and influence - and to integrate the only opponent, Hoechst, into the new network. By adopting this co-optation procedure, the BMFT managed to absorb the newcomer Hoechst into the leadership of the HTS policy network and averted threats to the otherwise accepted strategy of "universities first". This is quite evident in the committee's decision, finally approved by all industry members, to reserve 1988 funding for universities and postpone funding for industry until 1989 when more resources would be available. Instead of struggling over the own share in the funding budget, the efforts of the committee were focused on the provision of political legitimacy for the whole HTS program in order to expand future funding.

In summer 1987, even before the BMFT had applied for special money for HTS, the parliamentary committee for research and technology (Bundestagsausschuß für Forschung und Technologie) granted DM 12 million extra money for HTS research for 1988. This was a sort of national effort in reaction to the international competition and to newspaper reports. The parliamentary committee connected this special grant with the stipulation that a funding program for HTS research be submitted soon. The HTS advisory committee of the BMFT took part in the formu-

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[15] The BMFT only offered letters of intent to the industry. These LOIs were sent out in May 1988, stating that industry was expected to provide advance financing for HTS research for 1988 which would be reimbursed if there were funds left over in the ministry's budget at the end of the fiscal year.

lation of this funding program for HTS research which went through several checks during 1988 and was finally published by the project managing agency in February 1989. As far as can be investigated, the amount of public funding that was considered to be necessary by this funding recommendation was raised from DM 167 million to DM 390 million and the program duration from four years to seven years. This expansion of the program was a strong incentive for consent and compromise among conflicting interests within the committee representing the enlarged policy network.

In summer 1987 the old superconductor industry became aware of the newcomer Hoechst on the HTS scene. They realized that HTS was not only a domain of electronics and electrical industry but also a potential market for chemical corporations that could provide ceramic know-how. In contrast to its strategic exclusion of other chemical firms, Hoechst was very much interested in collaboration with component producers, with whom the competitive overlap was very small. Hoechst wanted to sell semi-finished products, wires, ribbons or films that the electrical and electronics industry would then use to manufacture devices (Chesnais 1988: 105; Fusfeld/ Haklisch 1985). Meetings between Siemens and Hoechst on possible collaborations started. Some time later Daimler-Benz/AEG indicated to Hoechst that they were interested in collaborating. Negotiations on the board level between the three corporations were initiated.

In autumn 1987 the BMFT was confronted with research applications from Hoechst, Siemens and AEG among others, which were similar in many respects. While parallel university research was definitely allowed (though under scrutiny) in the HTS program, parallel industrial research can not be financed by the BMFT. The high costs are prohibitive. The BMFT wanted to combine several projects to form large joint research projects, which would mean that all the firms involved would have access to each other's research results. They also wanted to ensure the compatibility of the research objectives of chemists and ceramists from the chemical industry and of physicists and engineers from the electrical industry. Faced with the problem of having to cut the proposals in some way to eliminate overlaps, the BMFT realized that its own informational base regarding strengths and interests of the corporations was too restricted and decided to ask the corporations themselves. They were all members of the advisory HTS committee, which may have been the site for some bargaining between BMFT and industry and within industry. The attempt of the BMFT to stimulate collaboration between the firms and between firms and university groups met with some resistance of industry, which was concerned about its autonomy in defining cooperative ties. They did not want to take advice from the ministry. The BMFT's stated aim was only to arrange the proposals in order to form joint research projects. This aim, along with the formation of the advisory committee, with the prospects of increased public funding for a national effort in HTS and with the companies' search for synergetic advantage and risk-minimizing approaches, finally triggered the formation of the German HTS consortium. In spring 1988 Hoechst, having consulted with Daimler-Benz/AEG and Siemens, gave a press conference and presented the research consortium, within which Hoechst once again has a central position. Collaboration with AEG/DB and Siemens is relatively easy for Hoechst (exception: Vakuumschmelze, a subsidiary of Siemens which manufactures superconducting wires), while cooperation between AEG and Siemens, which are direct competitors, is far more problematic. This is reflected in the later development of the consortium. The contract was finally signed by Hoechst and Siemens, while Daimler-Benz/AEG decided to have just an option to come in later. Hoechst not only is central in the industry network but also in the surrounding academic network. Hoechst has collaborative ties to fourteen academic partners, Siemens to seven partners and Daimler-Benz/ AEG to six partners. Even if one does not take into account the five partners for the search for new materials, Hoechst remains the corporation with the greatest access to external scientific experience in HTS research.

Hoechst has succeeded in building up a central position in the academic network and in becoming a member of an industrial consortium, pooling resources and minimizing the uncertainties of basic research, while at the same time remaining the only chemical firm in the network. Within the industrial collaboration they occupy a gate position that allows them to maximize the information flow, which is critical for success in basic research. They had this opportunity when they got to know about HTS very early by chance, and they took this chance without hesitating. While old network people were still recovering from the shock of HTS, Hoechst was making contracts with the top university researchers. From this position they were able to convince the BMFT of the necessity of funding joint industrial-university projects. Although the first plans to incorporate HTS into the material research program failed, the networking strategy proved to be error tolerant. It allowed Hoechst to enter the established network and to achieve a central position in the industrial consortium.

7 Summary and Perspectives

The discovery of HTS and the related changes in scientific and technological paradigms triggered a transformation of the old superconductivity policy network and gave rise to a new approach to HTS research policy. The HTS programs set up by the BMFT were largely determined by those actors who took advantage of two special opportunities created by the break in the superconductivity paradigm.

The change in the scientific trajectory could be handled within the old superconductivity policy network. It gave the impetus for the BMFT to set up a basic and interdisciplinary research program based on the university researchers of the old network. The external conditions for this network building by the BMFT were that the necessary combination of chemical/ceramic and solid state know-how was not available within the industry from the old network and that these firms agreed to rely on university research in a first program phase devoted to material science questions.

The second new opportunity deals with the break in the technological paradigm of superconductors that offered chances to sectors which had not been concerned with superconductivity before. Hoechst's arrival in the HTS network was partly a result of chance and even misconceptions - they found out about the first HTS meeting by chance, and were motivated by the false assumption that HTS would become a subject of the material research program. In the material research program, the superconductor industry would have been the newcomer; as it was, Hoechst was the newcomer to the superconductivity network. Despite this status, Hoechst shaped the evolving network with its strategic networking approach. The patent race and a technology exceeding the boundaries of any single industrial sector were the arguments for Hoechst to build up a network of collaboration with academic scientists. This starting position together with the technological importance of the chemical industry enabled Hoechst to convince the BMFT to set up a second program on industrial research, to monopolize the "new materials" aspect of HTS and to acquire a central and unquestioned position within the HTS industry consortium.

This chapter showed how an established policy network adapted to changes in the environment, in this case to a scientific and technological breakthrough. Old definitions of who and what belongs to the field could only be overcome by an extremely powerful and strategically planning actor entering the scene and pushing forward its definition of the problem. Further research in the analysis of the German HTS policy should be oriented to the question of whether public goals can be achieved within the structure that has emerged from this intersection of actor strategies and scientific and technological trajectories. In my view, there are two main problems:

- the efficient coupling of the various disciplines cooperating (and competing) in the university joint projects, and
- the efficient coupling of scientific and technological progress.

Contingent factors in the history of the HTS policy network have led to the emergence of two partly competing research programs and research networks: university-centered joint projects on the one side, and the industrial HTS consortium on the other. Whether the rather loose interaction between industry and university groups will result in an effective exchange of information and know-how is not yet clear. With one exception (ABB = Asea Brown Boveri, an electrical firm), the corporations refused the offer to join a university joint project, preferring to pick out some institutes for collaboration in the frame of their industrial projects. While the BMFT is interested in facilitating the transfer of scientific and technical know-how from the state universities to medium-sized and small firms that are expected to join the HTS program later, the large corporations are afraid of losing control over their know-how. Reluctant to collaborate with a wide range of university groups, the large corporations prefer to choose their partners on their own in order to limit the number of participants and to reduce coordination and control problems. They are not interested in creating the conditions of technology transfer in general but only in particular, in so far as the own company's concerns are affected.

Further research should be devoted to this relation between public and private goals in HTS research policy and to the role of network structures in their achievement.

References

Bernal, J.D., 1970: *Wissenschaft.* Reinbek bei Hamburg: Rowohlt (first edition 1954).

BMFT (ed.), 1987a: *Handbuch der Projektförderung.* Bonn.

BMFT (ed.), 1987b: *Förderkatalog 1986.* Bonn.

BMFT (ed.), 1987c: *Supraleitung - faszinierende Forschungsergebnisse und vielversprechende Perspektiven.* Pressemitteilung 49/87 vom 30.6.1987. Bonn.

BMFT (ed.), 1987d: *Neue Hochtemperatur-Supraleiter in der Diskussion.* Pressemitteilung 66/87 vom 18.8.1987. Bonn.

BMFT (ed.), 1988a: *Förderkatalog 1987.* Bonn.

BMFT (ed.), 1988b: *Bundesbericht Forschung 1988.* Bonn.

BMFT (ed.), 1989: *Förderkatalog 1988.* Bonn.

Böhme G./ Wolfgang van den Daele/ Wolfgang Krohn, 1972: Alternativen in der Wissenschaft. In: *Zeitschrift für Soziologie* 1, 302-316.

Böhme, G./ Wolfgang van den Daele/ Wolfgang Krohn, 1973: Die Finalisierung der Wissenschaft. In: *Zeitschrift für Soziologie* 2, 128-144.

Boswell, P.G./ R. Dornhaus, 1987: *The Economic Impact of High T_c Superconductors - a Materials Substitution Analysis for Potential Markets.* Frankfurt a.M.: Battelle.

Buckel, Werner, 1984: *Supraleitung. Grundlagen und Anwendung.*Third edition. Weinheim: Physik Verlag.

Burt, Ronald S., 1979: A Structural Theory of Interlocking Corporate Directorates. In: *Social Networks* 1, 415-435.

Chesnais, Francois, 1988: Technical Co-operation Agreements Between Firms. In: *STI-Review* No. 4, December 1988, 51-119.

Daele, Wolfgang van den/ Peter Weingart, 1975: Resistenz und Rezeptivität der Wissenschaft. In: *Zeitschrift für Soziologie* 4, 146-164.

Daele, Wolfgang van den/ Wolfgang Krohn/ Peter Weingart, 1977: The Political Direction of Scientific Development. In: E. Mendelsohn/ Peter Weingart/ R.D. Whitley (eds.), *The Social Production of Scientific Knowledge.* Dordrecht: Reidel, 212-242.

Daele, Wolfgang van den/ Wolfgang Krohn/ Peter Weingart (eds.), 1979: *Geplante Forschung. Vergleichende Studien über den Einfluß politischer Programme auf die Wissenschaftsentwicklung.* Frankfurt a.M.: Suhrkamp.

Dosi, Giovanni, 1982: Technological Paradigms and Technological Trajectories. In: *Research Policy* 11, 147-162.

Dosi, Giovanni, 1984: *Technical Change and Industrial Transformation.* London: MacMillan.

Elmore, Richard F., 1980: Backward Mapping: Implementation Research and Policy Decisions. In: *Political Science Quarterly* 94, 601-616.

Elmore, Richard F., 1985: Forward and Backward Mapping: Reversible Logic in the Analysis of Public Policy. In: Kenneth Hanf/ Theo A.J. Toonen (eds.), *Policy Implementation in Federal and Unitary Systems.* Dordrecht: Nijhoff, 33-70.

Fachlexikon ABC Physik, 1989, ed. by R. Lenk. Vol. 2. Frankfurt a.M.: Deutsch.

Farago, Peter, 1985: Regulating milk markets: corporatist arrangements in the Swiss dairy industry. In: Wolfgang Streeck/ Philippe Schmitter (eds.), *Private Interest Government. Beyond Market and State.* London: Sage, 168-181.

Fusfeld, Herbert/ Carmela S. Haklisch, n.d.: Kollektive Industrieforschung. In: *Harvard Manager. Innovationsmanagement,* Vol. 1. Hamburg: Manager Magazin Verlagsgesellschaft, 121-128 (English: Cooperative R&D for Competitors. In: *Harvard Business Review* 63 (1985), No. 6).

Galaskiewicz, J. 1985: Interorganizational Relations. In: *Annual Review of Sociology* 11, 281-304.

Grant, Wyn, 1985: Private organizations as agents of public policy: the case of milk marketing in Britain. In: Wolfgang Streeck/ Philippe Schmitter (eds.), *Private Interest Government. Beyond Market and State.* London: Sage, 182-196.

Grant, Wyn, 1991: Models of Interest Intermediation and Policy Formation - Applied to an Internationally Comparative Study of the Dairy Industry. In: A. Grant Jordan/ Klaus Schubert (eds.), *Institutions, Structures and Intermediation of Interest.* Special Issue of the European Journal of Political Research. Amsterdam: Elsevier (forthcoming).

Grant, Wyn/ William Paterson/ Colin Whitston, 1987: Government-Industry Relations in the Chemical Industry: an Anglo-German Comparison. In: Stephen Wilks/ Maurice Wright (eds.), *Comparative Government-Industry Relations.* Oxford: Clarendon Press, 35-60.

Häusler, Jürgen, 1989: *Industrieforschung in der Forschungslandschaft der Bundesrepublik: Ein Datenbericht.* MPIFG Discussion Paper 89/1. Köln: Max-Planck-Institut für Gesellschaftsforschung.

Hagedoorn, John, 1989: *Economic Theory and Analyses of Cooperation and Alliances in R&D and Innovation.* MERIT 89-006. Maastricht:

Maastricht Economic Research Institute on Innovation and Technology.

Hanf, Kenneth/ Theo A.J. Toonen (eds.), 1985: *Policy Implementation in Federal and Unitary Systems.* Dordrecht: Nijhoff.

Hazen, Robert M., 1988: *The Breakthrough. The Race for the Superconductor.* New York: Summit Books.

Hjern, Benny/ D.O. Porter, 1981: Implementation Structures: A New Unit of Administrative Analysis. In: *Organization Studies* 2, 211-227.

Hjern, Benny/ Chris Hull, 1982: Implementation Research as Emprical Constitutionalism. In: *European Journal of Political Research* 10, 105-115.

Institut für Sozial- und Bildungspolitik Hamburg e.V., n.d.: Abschlußbericht des Projekts *"Förderung der Zusammenarbeit zwischen Hochschule und Wirtschaft".* Hamburg.

Jaffe, Adam, 1989: Characterizing the "technological position" of firms, with an application to quantifying technological opportunity and research spillovers. In: *Research Policy* 18, 87-97.

Jansen, Dorothea, 1991: *Die Supraleitungsforschung und -förderung in der Bundesrepublik Deutschland nach der Entdeckung der Hochtemperatursupraleitung.* Research Report. Köln: Max-Planck-Institut für Gesellschaftsforschung (forthcoming).

Keck, Otto, 1984: *Der schnelle Brüter: Eine Fallstudie über Entscheidungsprozesse in der Großtechnik.* Frankfurt a.M.: Campus.

Kluge, Norbert/ Christoph Oehler, 1986: *Hochschulen und Forschungstransfer.* Kassel: Wiss. Zentrum für Berufs- und Hochschulforschung der GH Kassel.

Knorr-Cetina, Karin D., 1988: Das naturwissenschaftliche Labor als Ort der "Verdichtung" von Gesellschaft. In: *Zeitschrift für Soziologie* 17, 85-101.

Krempel, Lothar, 1988: *Netzwerke zwischen Forschungsorganisationen: Bericht aus einem Forschungsprojekt.* Manuscript. Köln: Max-Planck-Institut für Gesellschaftsforschung.

Krohn, Wolfgang/ Küppers, Günter 1987: *Die Selbstorganisation der Wissenschaft.* Wissenschaftsforschung Report 33. Bielefeld: B. Kleine.

Küppers, Günter/ Peter Lundgren/ Peter Weingart, 1978: *Umweltforschung - die gesteuerte Wissenschaft?* Frankfurt a.M.: Suhrkamp.

Kuhn, Thomas S., 1962: *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Kulina, Peter, 1988: Probleme und Perspektiven der industriellen Verbundforschung. In: *Technologietransfer. Forschung - Industrie.* Jülich: Dostall, 42-46.

Laumann, Edward O./ Joseph Galaskiewicz/ Peter V. Marsden, 1978: Community Structure as Interorganizational Linkages. In: *Annual Review of Sociology* 4, 455-484.

Lehmbruch, Gerhard/ Philippe C. Schmitter (eds.), 1982: *Patterns of corporatist policy-making.* London: Sage.

Luhmann, Niklas, 1968: Selbststeuerung der Wissenschaft. In: *Jahrbuch für Sozialwissenschaft* 19, 147-170.

Marsh, David/ R.A.W. Rhodes, 1991: New directions in the study of policy networks. In: A. Grant Jordan/ Klaus Schubert (eds.), *Institutions, Structures and Intermediation of Interest.* Special Issue of the European Journal of Political Research. Amsterdam: Elsevier (forthcoming).

Mayntz, Renate (ed.), 1980: *Implementation politischer Programme.* Königstein/Ts.: Hain.

Mayntz, Renate (ed.), 1982: *Implementation politischer Programme II.* Opladen: Westdeutscher Verlag.

Mennicken, Jan-Baldem, 1988: Spektrum der Forschungs- und Innovationsförderung in der Bundesrepublik Deutschland. In: *BDI-Handbuch der Forschung- und Innovationsförderung* 1, Erläuterungen 1, 1-21 (loose-leaf edition, February 1988).

Mersits, U./ H. Nowotny, 1989: *Striking Gold in the '90s: The Discovery of High Temperature Superconductivity and its Consequences.* Wien: Institute for Theory and Social Studies of Science.

Midtun, Atle, 1988: The Negotiated Political Economy of a Heavy Industrial Sector: The Norwegian Hydropower Complex in the 1970s and 1980s. In: *Scandinavian Political Studies* 11(2), 115-143.

Nakajima, Akira, 1988: Preparing for the Age of Superconductors: Experts Judge the Prospects. In: *Nikkei High Tech Report* 3(18), 1-4.

Nelson, Richard R., 1987: *Understanding Technical Change as an Evolutionary Process.* Amsterdam: North Holland.

Nöldechen, Arno, 1988: *Die Supraleitung. Nobelpreis für eine technische Revolution.* Düsseldorf: Econ.

Polanyi, M., 1951: *The Logic of Liberty. Reflections and Rejoinders.* London: Routledge.

Polanyi, M., 1968: The Republic of Science. In: E. Shils (ed.), *Criteria for Scientific Development.* Cambridge Mass.: MIT Press.

Politis, Constantin, 1987: Die Suche nach der Hochtemperatursupraleitung. In: *KfK-Nachrichten* 19, 119-129.

Rembser, Josef, 1987: *Das Forschungs- und Technologiesystem der Bundesrepublik Deutschland und ein Vergleich mit den Vereinigten Staaten, Japan und Großbritannien.* Paper presented at the international conference on "Die nationalen Forschungs- und Technologiesysteme westlicher Industrieländer - ein internationaler Vergleich" at the BMFT Bonn, 26-27 May 1987.

Rilling, Rainer, 1986: The Structure of the "Gesellschaft Deutscher Chemiker" (Society of German Chemists). In: *Social Studies of Science* 16, 235-260.

Rip, Arie/ Nederhof, Anton J., 1986: Between dirigism and laissez-faire: Effects of implementing the science policy priority for biotechnology in the Netherlands. In: *Research Policy* 15, 253-268.

Robyn, D. et al., 1988: Bringing Superconductivity to Market. In: *Issues in Science and Technology* 5(2), 38-45.

Schauer, F. et al., 1987: *Assessment of Potential Advantages of High T_c-Superconductors for Technical Application of Superconductivity.* Karlsruhe: KfK 4308.

Schimank, Uwe, 1988: *Institutionelle Differenzierung und Verselbständigung der deutschen Großforschungseinrichtungen.* MPIFG Discussion Paper 88/7. Köln: Max-Planck-Institut für Gesellschaftsforschung.

Schmitter, Philippe C./ Gerhard Lehmbruch (eds.), 1979: *Trends Toward Corporatist Intermediation.* London: Sage.

Schuh, Lothar, 1988: *Keramische Supraleiter.* Haar bei München: Markt und Technik.

Schulte, Peter/ Heinz Rüschenschmidt, 1987-1988: *Technologie- und Wissenstransfer an den deutschen Fachhochschulen.* 2 Vols. Ed. by the Bundesminister für Bildung und Wissenschaft. Bad Honnef: Bock.

Shrum, Wesley, 1984: Scientific Specialities and Technical Systems. In: *Social Studies of Science* 14, 63-90.

Shrum, Wesley, 1985: *Organized Technology. Networks and Innovation in Technical Systems.* West Lafayette, IN.: Purdue University Press.

Shrum, Wesley/ Robert Wuthnow/ James Beniger, 1985: The Organization of Technology in Advanced Industrial Society: A Hypothesis on Technical Systems. In: *Social Forces* 64, 46-63.

Simon, Arndt, 1987: Supraleitung - ein chemisches Phänomen? In: *Angewandte Chemie* 99, 602.

Slivka, Donald C. et al., 1988: *Ceramic Superconductors: Status and Opportunities.* Frankfurt a.M.: Battelle.

Smith, G.J. et al., 1989: High Temperature Superconductivity. Prospects and Politics. In: *Futures* 21, 235-248.

Smith, T. Fred, 1987: The Superconductivity Revolution? In: *Impact of Science on Society* 149, 15-24.

Streeck, Wolfgang/ Philippe C. Schmitter (eds.), 1985: *Private Interest Government. Beyond Market and State.* London: Sage.

U.S. Congress, Office of Technology Assessment, 1988: *Commerzializing High-Temperature Superconductivity.* OTA-ITE-388. Washington, DC: U.S. Government Printing Office.

Verie, Christian, 1988: The Technological and Economic Impacts of the New Superconductors. In: *STI-Review 1988,* 99-134.

Waarden, Frans van, 1985: Varieties of collective self-regulation of business: the example of the Dutch dairy industry. In: Wolfgang Streeck/ Philippe Schmitter (eds.), *Private Interest Government. Beyond Market and State.* London: Sage, 197-220.

Waarden, Frans van, 1990: *The genesis and institutionalization of national types of policy networks between the state and societal interests. A model for analysis and some historical comparisons between the USA and the Netherlands.* Paper presented at the ECPR Workshop "Institutions, Structures and Intermediation of Interests", Ruhr-Universität Bochum, 2-7 April 1990.

Wigand, R.T./ G.L. Frankwick, 1989: Inter-organizational Communication and Technology Transfer. In: *International Journal of Technology Management* 4, 63 ff.

Wilks, Stephen/ Maurice Wright (eds.), 1987: *Comparative Government-Industry Relations.* Oxford: Clarendon Press.

Williamson, Oliver E., 1975: *Markets and Hierarchies.* New York: The Free Press.

Williamson, Peter J., 1989: *Corporatism in Perspective.* London: Sage.

Windhoff-Héritier, Adrienne, 1980: *Politikimplementation. Ziel und Wirklichkeit politischer Entscheidungen.* Königstein/Ts.: Hain.

Wittrock, Björn/ Stefan Lindström/ Kent Zetterberg 1982: Implementation Beyond Hierarchy: Swedish Energy Research Policy. In: *European Journal of Political Research* 10, 131-143.