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CHAPTER 7

THE GERMAN INNOVATION SYSTEM

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1. BASIC ECONOMIC FEATURES OF THE GERMAN INNOVATION SYSTEM

Germany as a country with no natural resources (except coal) is traditionally driven by knowledge creation and technologies. It is characterised by a broad science and technology (S&T) infrastructure, a well-educated workforce, an export-oriented industry (large as well as small and medium-sized firms) and an active civilian government technology policy towards research and diffusion.

The contribution of R&D-intensive branches of industry to domestic product is much higher in Germany (12.2%) and Japan (11.5%) than in Great Britain, the US and France (7.7 to 8.5%). Germany is the leader in high-tech, ahead of Japan, whilst its significance in France and Great Britain as well as in the US and Italy is relatively slight. In Germany, even leading-edge technology contributes almost as much to the value-added of the entire economy as in Japan, and approximately as much as in the US (see NIW/DIW/ISI/ZEW, 1998). However, the 1990s marked a change, inasmuch as the research-intensive sector worldwide tended to shed jobs even faster than the other branches of industry. In West Germany and Japan, in particular, which were able to increase employment the longest, the loss of jobs in this phase took place fastest. In West Germany, all the jobs in technology-oriented industrial areas created in the employment upswing since the mid-1980s vanished within a mere three years. The growth and employment centres have shifted to the US and Great Britain in the 1990s, for only there (since 1992) has there been a renewed upwards trend in the research-intensive sector – with a booming domestic economic situation, favoured also not least by the proximity of strongly growing markets with high technology needs in South East Asia, with which the exchange of goods and technologies has markedly been intensified.

From 1980 to the mid-1990s, when dividing industrial sectors into three different R&D intensity categories, increases in the numbers of persons employed in Germany were registered only in branches of leading-edge technology and higher-quality technologies. The non-R&D-intensive industries have cut back on employees. For all categories, however, it is true that jobs have been lost since the great recession of 1992. To sum up, this means that the R&D-intensive industries are the potential winners of the structural change, but that they are also subject to fluctuations in the economic cycle, and for this reason they cannot be expected to exercise such positive effects on employment that they alone can cure mass unemployment. Growth of employment can be observed mostly with regard to high-tech start-ups and innovative services.

Not only ever increasing shares of the value-added, but also innovation potentials are shifting from industry to the service sectors. At the same time, an ever increasing number of employees within industry are carrying out (more highly skilled) service functions, whilst production intensity continues to decrease. In the future, there is little expectation that employment problems in Germany, as well as in many highly developed industrialised countries, can be solved by a rapid expansion of R&D-intensive industrial branches. The economic structure in the industrialised countries is shifting increasingly in favour of the service sector, which is a significant user of new technologies. This is also the case in Germany, which has been able to keep pace with the sectoral structural change. Above all, knowledge-intensive service firms are on the advance: more than a third of all wage and salary earners are employed in this sector. Success is increasingly dependent on the use of new technologies and of innovations. This creates new markets for technology producers (especially information and communication technologies, infrastructure facilities in the traffic and communications area, and medical technology). Technical change is oriented increasingly towards the needs of the service sector. In parallel, the significance of research and innovation activities is growing continually in the service sector: in the US a third, and in Great Britain a quarter of the technical knowledge of service firms is already based on their own R&D efforts. In Germany, company-oriented services are expanding fastest in those areas where there is a corresponding demand from innovative industries.

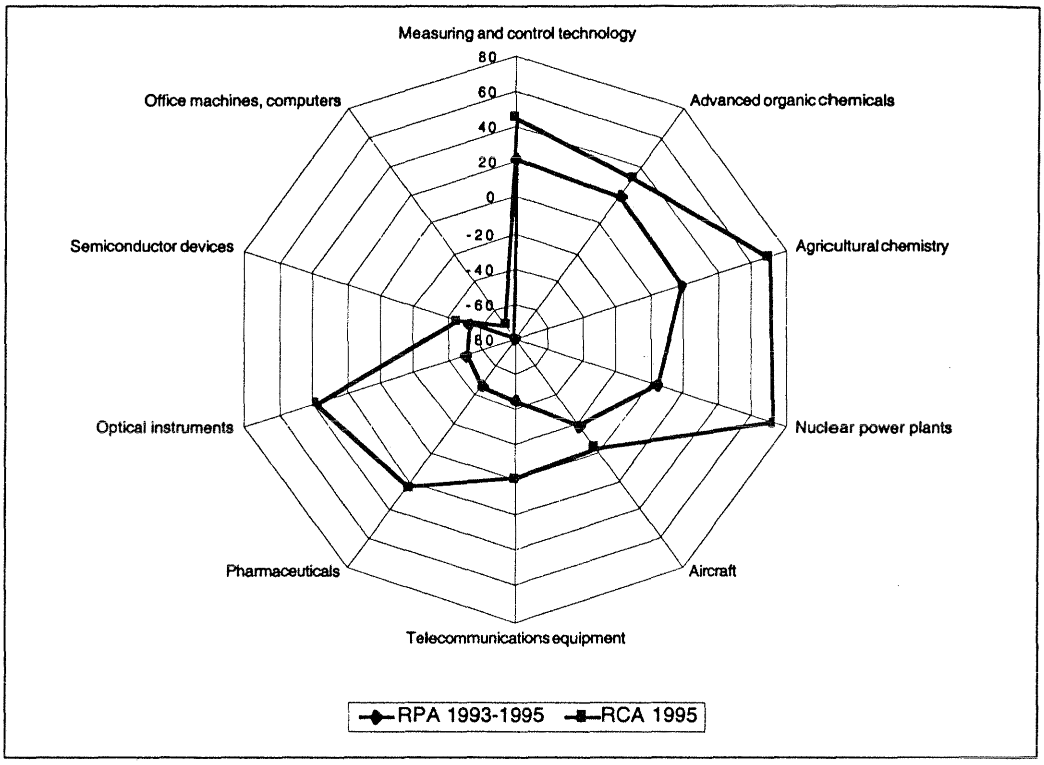
An analysis of the technological profile of countries and their deviation from the world average (Gehrke and Grupp, 1994) shows that smaller countries are very specialised, whereas larger countries display a spread in their profiles. The theoretical approaches of foreign trade theory and business administration, which regard the formation of own specialisation patterns as a worthwhile strategy for attaining comparative advantages, are confirmed here. A deviation can be determined for the EU, where, as a result of the European domestic market, the specialisation patterns between the individual countries are getting closer. When the industry branch specialisation in Germany is considered (Figure 7.1), it can be seen that particular specialisation advantages exist in the clusters surrounding vehicle construction, mechanical engineering and the chemical industry, whereas the sectors of the information technology (IT) industry are characterised by specialisation disadvantages across the whole scene[1] (see below).

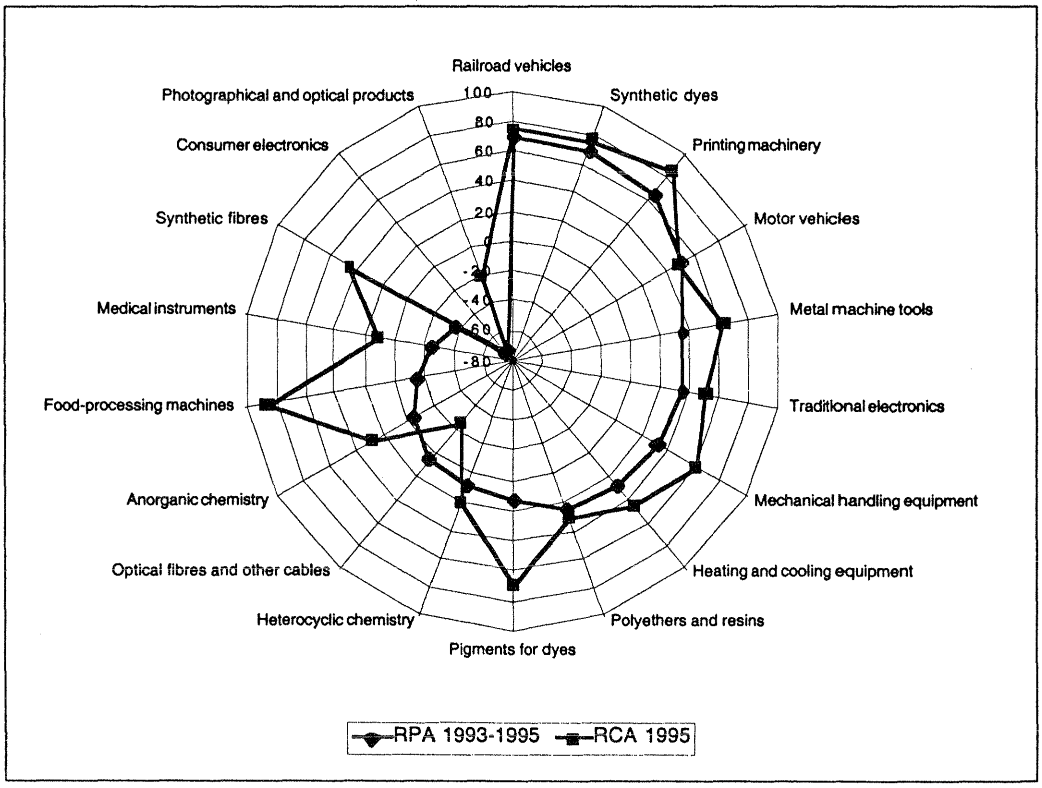
The strengths and weaknesses of the German innovation system are summarized in an extremely simplified fashion in Table 7.1 (see also NIW/DIW/ISI/ZEW, 1998; Krull and Meyer-Krahmer, 1996; BMBF, 1999). One of the strengths of the German innovation system lies in advanced technology branches, which were already identified in the branch specialisation (automobile and mechanical engineering, chemical industry). A barrier can be seen primarily in the failure to link up with the leading-edge technologies. The most important areas of leading-edge technology in the next ten years will be information technology, biotechnology and new materials. Due to the presumptive path dependency of innovation systems, it is of strategic significance to link the top technologies to the existing competences in the German clusters. The failure to link up with the top technologies goes hand in hand with a blockade of product and service strategies, as companies are still very much oriented towards their traditional concepts and product lines. The sectors find it difficult to integrate new products and technologies at the fringes. This makes the increasingly important cross-border and cross-sector activities more difficult. Nevertheless, a strong(er) specialisation in highly productive, company-associated services can be discerned.

Closely connected with this is the opening up and exploitation of new markets. Germany offers a very disparate picture in this respect: while markets

1. In addition, we refer to the comprehensive analyses of NIW/DIW/ISI/ZEW (1998) on the technological performance of Germany.

FIGURE 7.1 – Germany's technology and trade portfolio in R&D-intensive goods





Sources: EPO, FhG-ISI calculations.
Notes: Relative Patent Activity (RPA): a positive value indicates that the share of patents in this field is larger than for total patents.
Revealed Comparative Advantage (RCA): a positive value indicates that the export–import ratio is higher for the product group than for total manufactured goods.

TABLE 7.1 – Elements of the German innovation system

Strengths	Weaknesses
High-level technology	Inadequate link-up to leading-edge technology and to product/service strategy
Existing markets	New markets
Decentralised research system	Fragmented structure
High degree of internationalisation in R&D	Domestic orientation of technology policy
Qualified staff and workers	Drop in incentives to invest in training and education
Adoption of long-term orientation (entreprises, science, policymakers)	Inadequate incentive mechanisms, limitation to traditional fields

Source: ISI.

for environment-friendly technical solutions have been developed dynamically (not least because of the demand created by publicly-funded measures) and the environmental industry occupies a leading position, numerous new market developments are – especially in the area of communication and information technology – lagging far behind, when compared with the dynamism in the US, for example. There is no doubt that job creation opportunities have been neglected in these cases.

The research system in Germany is highly differentiated and decentralised (see section 2). Internationally, this is seen as a characteristic advantage of the German innovation system (Malerba, 1994), which should not be destroyed by extensive priority setting. Such a system, however, must be closely networked and exhibit sufficient flexibility and dynamic. This is not the case at present. There is a strong need to improve the system towards a competitive, flexible and high-quality public research infrastructure facilitating the practice of modern modes of knowledge production and offering excellent, user-oriented academic teaching.

The high degree of internationalisation of R&D is a plus point for Germany as a location. For the US, Germany is the most important foreign research location and in the EU countries, only in England do the Japanese conduct more R&D than in Germany. It is a generally perceived phenomenon in many developed industrial states that the globalisation of the markets and the internationalisation of R&D have been manifested relatively little in the national technology policies. The smaller countries have proved in the last few years to be more open than the larger countries, which, because of their inertia and their greater technical-scientific power, still have to embark on the necessary adaptation processes. In Germany, too, the national orientation predominates.

The availability of qualified personnel is an essential precondition for the strength under point (2) of Table 7.1. The decreasing willingness of companies to invest in training/education is a dangerous and general barrier. Fundamental suggestions for reform are needed here. Classical strengths (good infrastructure, human resources, education system, research) are still effective, but because of the increasing mobility of research and human resources, the acquisition of knowledge, and an efficient education system, as well as "lead" markets will become more significant. The institutional system of industrial relations (co-determination, autonomous wage bargaining) and trust and co-operation between management, banks and the participating workforce, lead to relatively small frictions when introducing innovations. However, there are still not sufficient firms prepared to risk start-ups or banks prepared to play a more offensive role, or private investors to finance innovation.

With regard to the long-term orientation of science, politics and industry, we can determine that this is drastically decreasing, compared to the 1970s and 1980s. A development of this kind is, as we see it here, the last of the fundamental barriers in the German innovation system. As today's product strategies and tomorrow's markets require learning processes over several years, it is of crucial importance to uphold farseeing strategies. This is especially significant for the decoupling, which is necessary in the long term, of resources consumption and growth, as well as for the target of achieving a sustainable economy.

2. PUBLIC AND PRIVATE RESEARCH LANDSCAPE

In Germany, S&T planning, policy-making and funding take place on such a wide variety of different levels, and there are so many institutional structures, that it is difficult to avoid oversimplification when one tries to draw a coherent map of the present system. Not only do we have a wide variety of institutional actors, but within each institution we also find quite diversified structures funded by a multiplicity of sources and consisting of many subsystems (Krull, 1991b, Keck, 1993, Schmoch, 1996, Krull and Meyer-Krahmer, 1996). All of these have their specific functions concerning the objectives, the resources and the amount of freedom granted to the respective scientific and technical staff in conducting research.

When looking at the total R&D budget (see Figure 7.2), one of the most striking features is that in 1997 more than two-thirds of R&D activities were carried out in industrial laboratories. Throughout the 1980s industry's share of R&D conducted steadily increased, and in 1990 it reached a share of more than 70%. Since then, according to the data available, industry's contribution has declined over the last years to around 67%. In contrast to France, private industry is, in this respect, by far the most important actor in the German innovation system.

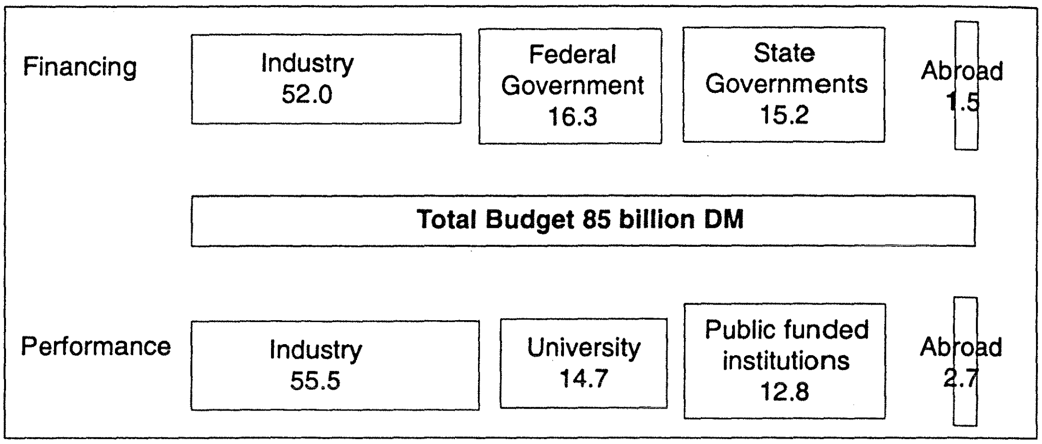
Due to the federal structure of the German state and the division of power anchored in the constitution (which assigns the individual state (*Land*) the task and authority of running the higher education institutions), a marked emphasis on the freedom and autonomy of science, and a market economy which fosters the initiatives of industry and private foundations, there is only limited room for centralised decision-making. However, the Federal Ministry for Education and Research (*Bundesministerium für Bildung und Forschung* – BMBF)[1] does take responsibility for the general principles and the legal framework governing the publicly financed areas of S&T. Figure 7.3 gives an overview of the actors performing R&D in the German innovation system.

2.1 – *Industry and its confederation*

In 1993 there was a total of about 11500 industrial businesses conducting research in Germany, of which some 9200 were based in the old *Länder* and 2300 in the new *Länder* (including East Berlin). About 90% of these research-performing companies employed fewer than 500 people each and thus fell into the category of small and medium-sized enterprises (SMEs).

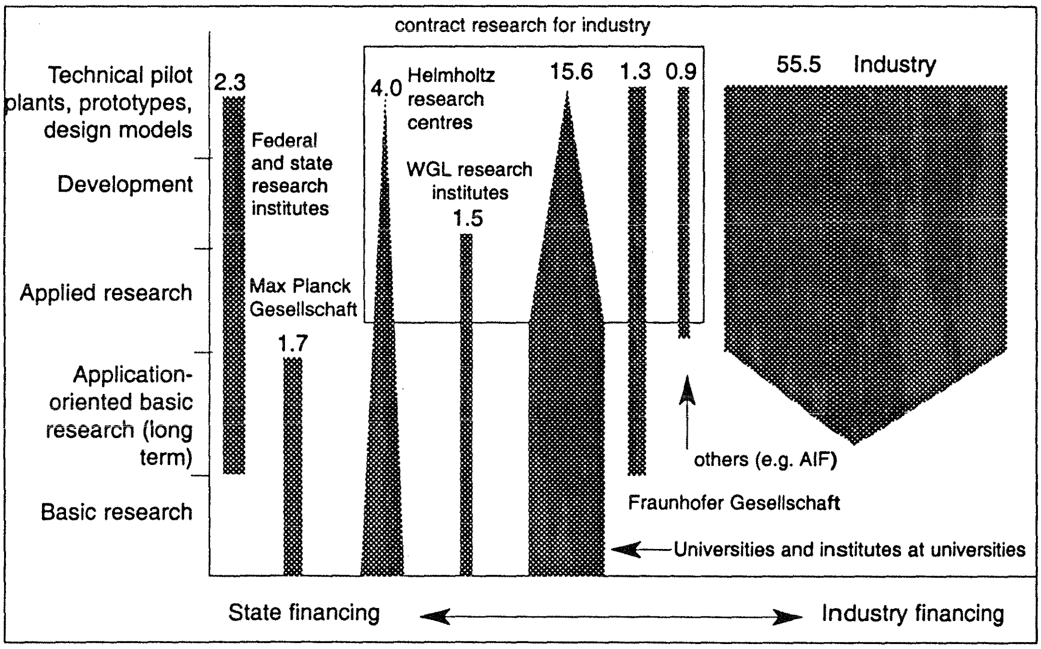
1. The responsibility for technology has been moved to the newly-named Federal Ministry of Economics and Technology (*Bundesministerium für Wirtschaft und Technologie* – BMWi), since October 1998 responsible for near market research and technology support.

FIGURE 7.2 – The German research budget (1997) – performance of R&D



Source: BMBF.

FIGURE 7.3 – The German research landscape (1997)



Source: BMBF. Design: IS.

However, a considerable number of companies are engaged in research on a regular, albeit discontinuous basis (i.e. a completed R&D project is not immediately followed by the next one) therefore, it is assumed that the research potential of the business enterprise sector is much greater. Estimates made by ISI suggest a total of about 25 000 companies.

Large companies account for 85 % of total intramural business enterprise expenditure on R&D, followed by SMEs with some 14 % (their share is rising). Looking at the total expenditure on R&D in Germany, one can see how important the business enterprise sector is for R&D. With shares of 62% (financing) and 67% (performance) in gross domestic expenditure on R&D in 1997 this sector is, quantitatively, the most significant R&D player in Germany. A comparison with the other G7 states shows that in terms of performing R&D this also applies to all other major industrialised countries. In the early 1980s intramural R&D expenditure in the business enterprise sector had double-digit rates of increase, which were considerably higher than those of government expenditure. This growth slowed down considerably during the rest of the 1980s, and the first half of the 1990s was characterised by a stagnation of this indicator. A similar slackening dynamism in R&D expenditure was also identifiable in the other major industrialised nations. With a probable increase of the business sector's intramural R&D expenditures of 5% between 1995 and 1997, this is the first growth in real terms since the 1980s. Financial R&D resources of the business enterprise sector comprise both intramural and extramural R&D expenditure. The total volume of the latter of about DM6.2 billion (1995) is low, compared with the former. However, their development in the period under review shows that their relative importance was increasing continuously.

R&D in the business enterprise sector is mainly performed in companies, but one must also consider the institutions for co-operative research and experimental development. These mainly include institutes set up by research groups formed by medium-sized companies, which make up the Confederation of Industrial Research Associations (AiF). In 1996 there were 109 such research associations with 57 institutes of their own and a total budget of around DM620 million. Co-operative research within the framework of the Federation of Industrial Research Associations (AiF) is an instrument to perform projects which surpass the capacity of single small or medium-sized enterprises (an extensive analysis of AiF can be found in Schmoch 1996). Those companies directly involved in the definition and supervision of projects benefit primarily from the results of co-operative research, but also technology transfer to other member companies is undertaken. A major focus of co-operative research is its limitation to pre-competitive problems, since several companies in the same subsector of industry have to co-operate. Nevertheless, in some industries the ratio of co-operative research to their total R&D activity is quite high. However, intensive use of co-operative research primarily concerns less research-intensive branches, whereas in research-intensive industries such as chemistry, electrical engineering and aeronautics the role of co-operative research is negligible.

2.2 – *The universities and Fachhochschulen*

The backbone of the German public S&T system (which accounts for the largest share of the publicly-financed part of research activities) is the universities. All in all, there are 84 of them. They are to a large extent financed by the state governments and have a threefold mission: educating students, training doctoral students and researchers, and carrying out research. The unity of research and teaching is an important characteristic of German universities. The training of students both provides the universities with a new generation of young scholars, and constantly gives fresh impetus to university research. By training students and researchers, the universities contribute to all non-university research activities and act as a stronghold of basic research.[1]

Even though there are differences from university to university, it can rightly be said that in no other scientific institution in Germany is the spectrum of different research activities so broad. Such diversity means that research at universities – particularly in the humanities – is pursued in relatively small units. Research projects involving just one or a few scientists are frequent and large-scale projects in S&T are seldom found at universities. This division into numerous small units makes it easier for the universities to cover a wide range of research in a variety of individual projects. On the other hand, this creates problems as far as their ability to contribute to the solution of complex issues entailing high expenditure over a long period is concerned. As the requirements of research (particularly the need for expensive equipment in the sciences, biomedical research and engineering) are constantly mounting, the concept of differentiation and specialisation is increasingly making progress. Now there is a remarkable consensus that concentration of efforts must be achieved among the universities.

In addition to the research carried out at universities, in recent years more than 220 *Fachhochschulen* (a specifically German type of higher education institution, especially in technical, managerial and social subject areas) have played an increasingly important role in training students as well as in S&T, especially in technology transfer at local and regional levels, in qualified consultancy for industry, in further training as well as in creating a link between regional requirements and applied research. They have become important contact points and providers of information, especially for small and medium-

1. An extensive description can be found in Krull and Meyer-Krahmer (1996).

sized enterprises. With their specific role in application-oriented R&D, the *Fachhochschulen* can complement the university research system. Research and development activities at *Fachhochschulen* largely depend on external funds and technology transfer revenues.

2.3 – The Max Planck Society and its Institutes

The *Max-Planck-Gesellschaft zur Förderung der Wissenschaften* (MPG) is a non-profit research organisation founded in 1948 as a successor to the *Kaiser-Wilhelm-Gesellschaft*, which was originally established in 1911. Institutes, research units and working groups run by the MPG are mainly devoted to basic research, to a large extent in the natural sciences and, to a smaller extent (about 14%), in the humanities. In contrast to the higher education system, which must cover all academic disciplines and employs some 102 000 academics (among them some 30 000 professors), the MPG can concentrate its funds and energy on selected key areas of basic research. In 1997, the MPG employed some 11 175 people in its research establishments (including 3015 scientists). In addition there are some 5700 fellows and guest scientists – almost 40% of them from abroad – who work at the 70 Max Planck institutes each year.

In its support of basic research, the MPG is highly selective. It does not primarily attempt to close national gaps in research, but tries to give strong, concentrated support to a few carefully selected fields. In this respect, the MPG proceeds from the following principles:

- The MPG takes efficient, widespread university research for granted, and pursues basic research in order to complement the research efforts of the universities (the principle of subsidiarity – which also applies to other areas of non-university research).
- The MPG supports basic research in particularly promising fields requiring interdisciplinary approaches, a great deal of institutional flexibility and international orientation. It tries quickly to embrace newly developing fields outside established disciplines (the principle of emerging fields).
- In order to fulfil its function, the MPG requires outstanding scientists who are particularly qualified for the position as head of their respective departments or institutes. For every new initiative, it is crucial to find researchers whose past achievements provide proof of their outstanding innovative capabilities and who can be expected to use the freedom and the research opportunities offered by the

position as a scientific member and director of a Max Planck institute to make exceptional progress (the principle of the eminent scientist or 'Harnack principle').

2.4 – The Hermann von Helmholtz Association of National Research Centres

The *Hermann von Helmholtz-Gemeinschaft deutscher Forschungszentren* (HGF – formerly, the *Arbeitsgemeinschaft deutscher Großforschungs – einrichtungen*) comprises 16 national research centres, which in 1997 had a combined budget of DM4.2 billion, 90% provided by the Federal Government and the rest by the Government of the state in which the respective centre is located, and some 25 000 personnel (including some 10 000 scientists). The national research centres cover a wide spectrum of R&D, ranging from basic research (in high energy physics, biomedical research, the marine sciences and so on) through mission-oriented or strategic research (aerospace, information technology, biotechnology and so on) to development of industrial technology (in areas like microelectronics, nuclear safety and super computers). These centres also operate big machines (for example neutron sources, accelerators, colliders, super computers, wind tunnels), which to a large extent are used by university researchers.

The national research centres are legally independent bodies, usually taking the form of a limited company or a foundation, with a reasonable amount of autonomy in relation to determining their research priorities. However, Federal Government authorities provide general guidance (*Globalsteuerung*) and use supervisory boards for laying down the overall objectives of research and the extent of core funding. It is mainly the BMBF which co-ordinates the work of the national research centres and, through its priority programmes, influences the process of priority-setting within each of the centres.

2.5 – The Fraunhofer Society (FhG)

A special role has been assigned to contract research, through the establishment of the Fraunhofer Society and its institutes. The *Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung* (FhG) operates a network of 47 institutes with some 8000 personnel, a third of them scientists, and a 1997 budget of DM1.3 billion. Its primary task is to carry out a broad range of strategic and applied research for government and industry. The institutes perform contract research and offer information and services related to new technologies, products and processes.

The Fraunhofer institutes receive public core funding (90% from the Federal Government and the rest from the government of the state in which the institute is located), but the actual budget depends on the amount of money earned by the institute through contract research. If the institutes meet the targets agreed for contract income (usually a fixed proportion of the overall budget, varying between 70% and 80%) they enjoy considerable autonomy. Since 1973, when it was decided that the basic funding of the FhG should be financed jointly by the Federal and the State Governments, this has been the fastest growing sector of non-university research. Over the 15-year period 1975-1990, on average, one institute a year was set up in West Germany after consideration of detailed proposals on needs and opportunities. As a result of the restructuring of the East German research institutions, in 1990-1991 the FhG set up 15 new research institutes and R&D groups in East Germany.

The most important criterion for setting up a new institute or an R&D group is whether the demand for contract research in a given field (for example microelectronics, information technology, production engineering, advanced materials, environmental research, innovation studies) will support an institute in two or three years' time. Fraunhofer Institutes have become important catalysts, above and beyond their own activities, in the process of transfer of technology from basic research institutions to industry. As small and medium-sized enterprises, in particular, benefit from co-operation with Fraunhofer Institutes (by increasing their rate of innovation), they are increasingly being seen as an important part of the publicly-financed R&D infrastructure for regional development. Therefore, the FhG is expected to contribute to the innovative strength of German industry:

- it should help to identify innovation potential at an early stage by closely watching and fostering technological developments;
- it should meet the demand of industry for specific long-term contract research and technical assistance;
- it should adapt its tools and abilities to meet the requirements of the research market, and perform research work for public-sector clients.

2.6 – The Gottfried-Wilhelm-Leibniz Association of Research Institutions

The *Gottfried-Wilhelm-Leibniz-Gemeinschaft der Forschungseinrichtungen* (formerly *Blaue Liste* institutes) comprises 82 research institutes, which differ very much in terms of function, size, location and legal structure. Apart from a number of institutes in the humanities, most of the Blue List Institutes are either mission-oriented research institutes in the sciences and the humanities, or service institutions (such as the Information Centre for Chemistry in Berlin, the Library of Technical Information at Hanover, and the Central Medical Library at Cologne). These institutes have to meet the following requirements: the annual budget must exceed DM2.5 million (or DM1.8 million, if the institute is mainly operating as a service institution for other researchers), the institute's work must be of importance above regional level, and should be in the interest of the Federal Republic of Germany as a whole. In 1997, the 82 institutes had a total budget of DM1.7 billion and some 12 000 personnel. Roughly 50% of their budget is usually provided by the Federal Government, and the rest comes from either the government of the state in which the institute is located or from all of the states (in the case of a service institution).

After the huge expansion of the Blue List sector in 1992 (some 34 new institutes in the new *Länder* were added to the previous list), the Science Council prepared recommendations for the restructuring of the Blue List and, as a consequence of these recommendations, evaluated the performance of all of the Blue List institutes, including a statement concerning the fulfilment of the above-mentioned criteria and a recommendation on whether joint funding of the institutes should be continued or not.

2.7 – Private foundations

All in all, there are some 900 private foundations offering support for higher education and research in the order of DM500 million per year. Most of these foundations are quite small, with a capital stock of less than DM1 million and revenues which only allow for small-scale activities such as a few scholarships or a prize for specific achievements. However, they add a pluralistic note to the German S&T system, and often encourage researchers to pursue non-conformist, high-risk projects which otherwise might not get funded. Some of the major foundations such as the *Robert-Bosch-Stiftung*, the *Thyssen-Stiftung*, and the *Volkswagen-Stiftung* (which is by far the biggest foundation offering support for higher education and research in the order of DM100 to 150 million per year) as well as the *Humboldt-Stiftung* and the *Stifterverband für die Deutsche Wissenschaft* are strongly committed to international co-operation in S&T, and offer a wide variety of funding opportunities for foreign scholars.

2.8 – Military research

The Federal Government's position on military research is that if Germany's Federal Armed Forces are to perform their mission credibly and play their role in the Alliance effectively, they have to be equipped with state-of-the-art technology. Defence research and technology use the results of civil research in order to tackle specific defence issues. The funding for such research, which is also within the framework of international co-operation, is provided by the Federal Ministry of Defence. All in all, military R&D with an overall budget of around DM3.0 billion (1997) plays a rather minor role in Germany.

Other actors in the German system of innovation, such as the Federal and *Länder* research establishments, play specific roles in providing research results to be used for policy making or administration and are discussed in Section 3.

3. POLICY PRIORITY SETTING AND GOVERNANCE

Germany has a decentralised and diversified research system. Against this background, it is not surprising that German R&D policy relating to industry over the last decade was described as "diffusion oriented" rather than "mission oriented" (cf. Ergas 1987). A strategic industrial policy with definite missions, such as that pursued in France, can hardly be implemented in a decentralised research system. Since the 1950s, German R&D policy – as in other Western European industrialised countries – has continually extended the scope of its activities. In the 1950s, the core area of R&D support comprised the (basic) university research financed by the *Länder* and the special area research carried out in federal and state governments' research establishments. Large technology programmes were added from the mid-1950s onwards, showing a marked orientation towards goals similar to those of the US, mainly in the fields of nuclear technology, aerospace and data processing, and later microelectronics.

From the beginning of the 1970s, in order to create and support the conditions necessary for the export of technology-intensive goods, public funding flowed into research projects of industry and institutes for applied research to promote cross-sectoral technologies (for example materials), key technologies (for example microelectronics) and technological systems (for example transport systems). During the 1970s, the reform policies of the government of the Social Democrats complemented these policies with research activities in the areas of environment, public health and working conditions. Increasingly, the diffusion of technologies came into the focus of policy. This includes the support of R&D activities, the strengthening of the infrastructure for the support of technology transfer from the science system into industry, as well as the support of SMEs and less-developed regions. In the 1980s increased internationalisation and the technology race within the "Triad" enforced the support of exploitation of the research system and the creation of new firms. In the 1990s the reunification of Germany and new modes of priority actions dominated the policy agenda.

TABLE 7.2 – Instruments of national technology policy

In a narrow sense	In a broader sense
1. Institutional promotion: - national research centres; - Fraunhofer Society; - Max Planck Society; - higher education institutes; - other institutions.	4. Public demand: Use of public institutions to increase market pull for "desirable" technical developments, e.g. environment-friendly consumer goods (recylcing paper, "eco" car).
2. Financial incentives: - indirect promotion; - indirect-specific promotion; - R&D projects; - risk capital.	5. Issues concerning company strategy: - orientation knowledge and long-term visions; - technology assessment; - technology council; - to increase awareness of the importance of innovations.
3. Other infrastructure plus technology transfer via: - technology centres; - information and consulting; - demonstration centres; - co-operation, networks and change of personnel (e.g. change of jobs).	6. Education and training: Early arrangement of training opportunities for potential needs. 7. Regulatory policy measures: - competition policies; - legal framework; - influence on private demand.

Source: ISI (Meyer-Krahmer and Kuntze, 1992).

Since the 1980s the federal states have increasingly promoted R&D and innovation within regional industry. This can be illustrated by support for SMEs. Within the federal constitutional framework, state governments have the general responsibility for supporting SMEs. Financially stronger states, such as Baden-Württemberg or North Rhine Westphalia, have developed a fairly systematic and substantial set of innovation support programmes, whereas less-developed states, such as the coastal states, have not been able to do so. It should be noted that the state ministries for education provide limited funds to universities for the running of industry liaison offices.

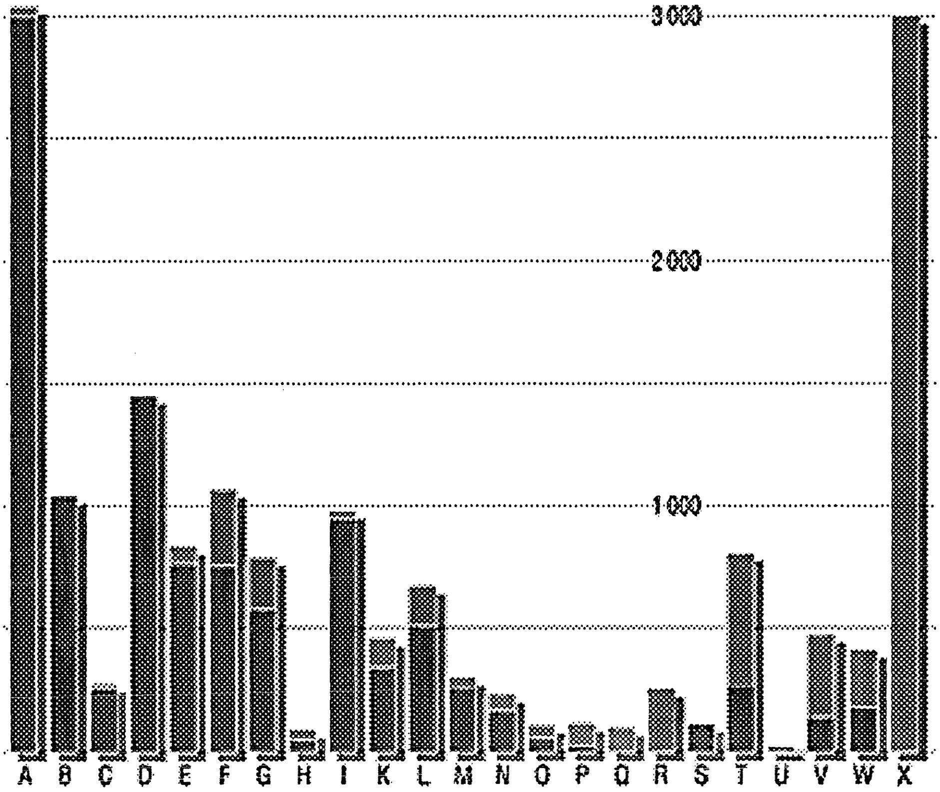
In the meantime, public technology and innovation policy in the Federal Republic of Germany has become one of the most important arenas for tackling economic structural change, modernising the national economy and, increasingly, meeting challenges to society. Tighter public budgets, the control requirements of Parliament, the Commission of the European Communities and the need for policy administrators to learn by using the new policy instruments, have led to a strong upswing in the evaluation of technology policy programmes and instruments in Germany. The main aims of federal technology policy in Germany are to:

- continually broaden knowledge about mankind and its natural environment, and to offer new orientations;
- create conditions that will strengthen the husbanding of resources and the environment;
- improve living and working conditions;
- increase economic performance and competitiveness.

The most important approaches and instruments of current German technology policy include (see Table 7.2):

- regulatory intervention (such as regulatory policy, technical norms and protective regulations);
- financial incentives (promotion of research and development and other innovative projects within enterprises by direct support or tax measures, promotion of co-operation of enterprises with public or semi-public research institutions);
- promotion of public demand for innovative products (procurement by the public sector);
- building up the public and semi-public infrastructure (such as provision of research and development institutions, technology transfer institutions, advisory institutions);
- support for the formation of consensus on technical developments in the economy and society.

FIGURE 7.4 – Federal R&D expenditure by funding area (1997)



Funding area

A University supporting organisations (construction and special programmes)
B Large-scale equipment for basic research
C Marine and polar research and technology
D Space research and technology
E Energy research and technology
F Environmental and climate research
G Health research and development
H R&D on working conditions
I Information technology (including multimedia and production engineering)
K Biotechnology
L Materials research; physical and chemical technologies
M Aeronautical research
N Research and technology for ground transport (including traffic safety)
O Geosciences and raw materials supplies
P Regional planning and urban development, building research
Q R&D for the food sector
R R&D in agriculture, forestry and fisheries
S Educational research
T Innovation and improved basic conditions
U Specialised information
V Humanities, economic and social sciences
W Other activities not assigned to other sectors
X Defence research and technology

Unit: Million DM.
Source: BMBF, Facts and Figures 1998.
Note: In black BMBF budget, in grey, other Ministries.

The Federal Government's R&D activities can be subdivided into specific subject-related funding areas and priorities, based on the Federal Government's R&D planning system, irrespective of which federal department finances the activities, and irrespective of whether the funds involved are tied to specific institutions or projects or whether the activities are contributions to international research programmes. This structure is illustrated by Figure 7.4, which provides an overview of the Federal Government's R&D spending (budgeted for 1997) in the various funding areas.

Departmental research is aimed at obtaining scientific findings which are directly related to the fields of activity of a given ministry or department. Such findings are used as a basis for decision-making to ensure proper execution of departmental functions. If the general status of knowledge is not sufficient for this purpose, the necessary research activities will be carried out, primarily by federal institutions. In the area of responsibility of the Federal Ministry of Transport, for instance, the technical rules for the expansion of the federal networks of roads and waterways are continuously being optimised. The Federal Institute of Physics and Metrology, which is under the responsibility of the Federal Ministry of Economics, carries out a considerable amount of research aimed at continuously optimising the status of public metrology and testing, in response to increasingly demanding requirements. If research is to be conducted by external institutions, precise terms of reference are set out, and contracts for the corresponding research projects are invariably awarded on the basis of public tenders. It goes without saying that there is overlap between the R&D activities of the various ministries. In the interest of research efficiency and in order to avoid duplication, it is therefore necessary to co-ordinate the research efforts made by the various ministries involved. The Federal Government's Co-ordination Concept has been developed for this reason. Its primary objective is to co-ordinate the contents of research activities, which also includes the development of co-operative research programmes for several ministries (government programmes). Such programmes are currently in operation in several fields such as health research, work and technology, and aeronautical research.

Responsibilities in the area of research promotion are divided between the Federal Government and the state governments according to the federal system, as determined by the Basic Law. According to Article 30 of the Basic Law, the exercise of state powers and the fulfilling of state functions – including those relating to the state promotion of research – are a matter for the state governments, unless otherwise stipulated or allowed for by the Basic Law itself. According to the distribution of powers laid down in the Basic Law, the Federal Government is responsible, among other things, for the legislation relating to the promotion of scientific research (Article 74 No 13 of the Basic Law); it has not, however, availed itself of its power to issue a general research promotion law. The power of the Federal Government to issue framework regulations concerning the general principles of the university system (Article 75 No 1a of the Basic Law) is also relevant to university research. Most of the R&D expenditure of the states goes to the universities (around two-thirds).

In addition, intermediate bodies like the Federal State Commission for Educational Planning and Research Funding (*Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung* – BLK) and the Conference of Ministers of Education and Science (*Kultusministerkonferenz* – KMK) take on responsibility for co-ordinating higher education and research policy matters across the Federal Republic.

Usually, the co-operation of the federal and state authorities is quite close, and the consensus mechanism for decision-making in the intermediate bodies paves the way for more and more jointly funded institutions and programmes. However, it should be noted that the federal as well as the state governments also run their own laboratories, especially in areas where the implementation of regulations and standards needs to be supervised, for instance in health and environmental research, but also in materials and other industrial technologies.

3.1 – The Science Council

The Science Council (*Wissenschaftsrat*) is a science policy advisory body set up in 1957 to advise the German federal and state governments on all matters of higher education and research policy. Its main function is to prepare reports and recommendations on the structural development of German universities, *Fachhochschulen* (Technical Colleges), and research institutes, and on important aspects of higher education in general. Reports and recommendations are prepared in committees and working parties made up both of academics and of representatives of federal and state governments. The Science Council has an explicit mandate to consider the quantitative and financial implications of its proposals as well as problems related to their implementation. Prominent activities of the Science Council in the 1990s were advice on the restructuring of the former East German innovation system after German unification, advice on the development of higher education in the 1990s, on the establishment of centres of excellence in selected research fields, to forecast the availability of, and demand for, research personnel in universities, *Fachhochschulen* and society at large, or to evaluate research institutes. The Science Council regularly publishes reports and statistical material on various aspects of the higher education and research system, which can be obtained from its headquarters in Cologne.

3.2 – The German Research Association

The German Research Association (*Deutsche Forschungsgemeinschaft* – DFG) serves all fields of science, engineering and the humanities by financing research projects and offering scholarships. It performs this task as an autonomous self-governing body within the German research system. Scientists and scholars choose their own subjects for research, and through electing their own peer reviewers, contribute their influence to decisions on resource allocation in universities and research institutes. It receives close to 100% of its funds from public sources. Roughly, 60% of a total of around DM2.1 billion come from the federal government, chiefly the Ministry for Education and Research (BMBF), and 40% from the 16 state governments.

The DFG spends approximately half of its funds on individual, unsolicited investigator-initiated projects where proposals are usually reviewed by mail (*Normalverfahren*). Almost 30% of its funds are spent on some 200 research centres (*Sonderforschungsbereiche*), which are reviewed by site-visits at three year intervals. In this case, proposals must come from universities (as institutions), but are otherwise unsolicited. Nearly 20% of its funds are spent on solicited, individual investigator-initiated projects in co-operative research programmes usually called priority programmes (*Schwerpunktprogramme*) for which panel review following proposal discussion with the applicants is normally used. All funding decisions on more than 12 000 research projects per year rely on peer review.

3.3 – Re-evaluation of the role of public research

When in October 1990, after more than 40 years of separation, the two parts of Germany were legally unified, there was great enthusiasm for jointly rebuilding the nation, and there were even higher expectations concerning the improvements that could be made over the next five or six years. Like many other areas of the political, economic and social systems developed after World War II in the Federal Republic of Germany (FRG) and the German Democratic Republic (GDR), science and technology (S&T) did take different courses.

While the West German S&T system was established along federal lines, with primarily decentralised ways of decision-making based on freedom in teaching and research, and on the autonomy of higher education institutions and science organisations funded by many sources, the GDR structured its S&T system according to the Russian mode.

In comparison with the GDR's S&T system, the federal, democratic structures of S&T support in West Germany appeared to present virtually no problems. Therefore, it seemed that those East German policymakers and politicians who won the first free elections in spring 1990 wanted to introduce an S&T system similar to the West German one. Nevertheless, several reports revealed many unsolved problems, deficiencies, organisational shortcomings and inherent contradictions in certain sectors of the S&T system in West Germany. It seemed only logical that the West German Science Council, when asked by the East German government to conduct an evaluation of the research institutes and to prepare recommendations for the restructuring of the entire S&T system, wanted to use its previous analyses of shortcomings in the West as a basis for the development of new concepts which could be valid for both parts of the country.

While the deficiencies of the West German system were well known, basically the West German system was adopted in East Germany, with unification, and none of the indigenous elements survived.

In the 1990s the German Federal Government started a series of different exercises of re-evaluation of the role of public research. Among them was the setting-up of a non-permanent commission on the future of basic research and larger laboratory facilities. Although reluctant to perform a thorough research forecast the commission gave, however, very concise and guiding recommendations, most of which have had decisive influence on governmental science policy decisions. The departments of the Federal Ministry for Education and Research have continued to refer to the advice of the commission. For example, action was taken to push Germany to the front of bioscience research by the end of the 1990s. Another example of this commission still casting a long shadow is the National Health Council updating the relevant subject of medical research.

The roles which the large national multidisciplinary research centres at Karlsruhe and Jülich should play, had been discussed for years, especially that part of their work that was intended to be directed towards innovation goals in important technological fields. Therefore, industry was asked by the BMBF to examine the technological power and capacities of these two research centres and to recommend how to improve partnership and co-operation in a long-term planning process. The committee known as the 'Weule Commission' called for at least a doubling of the proportion of innovation-oriented research, as being of possible importance for economic competition.

Unification of the two German systems and the previously started debate on the functions of public research, in the end, led to a common vote (in 1996) of the conference of the Federal Chancellor and the state Prime Ministers to undertake an evaluation of major parts of the German innovation system. Those organisations that are jointly funded by the federal and state bodies – the Max Planck Society, the Leibniz Institutes ("Blue List"), the German Research Association, and the Fraunhofer Society – should be assessed in view of their role and position in the national system of innovation (hence "system evaluation"). The following general conclusions emerge from this evaluation of the German public R&D system:

- there is a need for public sector R&D institutions to respond faster to changing competitive environments, which requires more systematic strategic planning;
- more interdisciplinarity is needed to cope with questions of large impact in systems of growing complexity;
- for a faster adaptation of research results as well as for a clearer understanding of results needed, more thorough links in the chain of basic research–higher education research, as well as extra-university research–industry is needed;
- as a means to achieve these goals, the introduction or intensification of internal competition in the organisations of public research is being discussed; and, finally,
- a restructuring of the salary system is being proposed to allow for more performance orientation.

The increasing technological change and the globalisation of the markets, as well as the special situation after the reunification of Germany with its severe budget restraints made the responsible persons at the BMFT change their minds (Martin, 1995). Longer-term perspectives and strategies to make better use of the limited resources were sought. The selection of support and more goal-oriented prioritisation of certain technologies seemed to be necessary. On the other hand, the state had to be careful not to intervene too much in the market and its self-regulating forces, or in the self-organised science system.

In the beginning of the 1990s, the necessity of concentrating their resources made all parties more interested in foresight and therefore some long-term prospective studies were commissioned in 1991, in order to get some early indications of the most promising developments in science and technology.

After years of considerable investments in basic science facilities and also in large technological projects, the German Federal Government started once more to reflect upon the role of the national laboratories, the question of how to focus limited resources on the most promising fields of basic research, and how to optimise the interaction between science and industry during the innovation process (see Cuhls, Uhlhorn and Grupp, 1996, p. 76). In 1994, the German Science Council recommended a foresight process guided by the science community itself and with the ambition of becoming recognised in a partnership with industry and government.

In 1990 the German Federal Government started a series of different foresight exercises. From the beginnning, it was intended to involve most of those persons, who supposedly should have had deeper insights into technological trends emerging out of new research results. As a subsequent objective, new ideas should be transported to a wider public to initiate creative discussions. As a major step forward towards a national policy, a strategic panel was established where all three parties involved – science, industry and government – could exchange arguments and clarify positions with regard to R&D priorities. In spring 1995, Chancellor Kohl set up a Council on Research, Technology and Innovation, which finished the first round of deliberation with recommendations on action in the sector of the information society. In 1996, work on bioscience began (the Council was abolished when the new Government was elected in 1998). Reports of the Council have covered the topics of the information society, biotechnology and competences for global competitiveness. Parallel to this, the Parliament has set up a commission of inquiry (*Enquete Kommission*), therefore guaranteeing an independent view of the legislative body.

4. PRIORITY PROGRAMMES AND THE SUPPORT TO SME

In its 1996 report on research, the Federal Government outlined its perspectives on research and technology policy under the heading "Making the future possible", and assigned the following central objectives to it:

- promotion of high technologies as drivers of innovation;
- innovation-oriented research policy;
- cultural vitality and performance;
- research to provide for and shape the future;

- safeguarding and improving scientific excellence;
- strengthening and networking the research system;
- developing the research system in Germany's new *Länder* (states);
- internationality and international co-operation.

From these objectives the following "visions for a future-oriented research and technology policy" were derived:

- high technology for manufacturing and services – opportunities for more employment;
- number one in Europe – opportunities for Germany offered by biosciences and biotechnology;
- growth through knowledge: the future of the information society;
- energy and the environment;
- mobility – decoupling growth and economic resource consumption;
- competitiveness through international co-operation.

New technological developments are increasingly produced at the boundaries of traditional disciplines and entrepreneurial core competences. Often they are so complex that a single business enterprise cannot provide all the know-how resources required to cope with the tasks in hand. In particular, in those cases where companies need to combine highly different technology areas, at the same time involving public research institutions and SMEs (for example microsystems, and the versatile use of new materials), high risks and communication problems obstruct the further development of technologies and their applications.

4.1 – The support to "lead projects"

Acting as a facilitator, the Federal Government supports the process of innovation by funding such projects. The joint participation of several companies and research institutions in research networks helps to make more efficient use of scarce research capacities, to accelerate the technology transfer between science and industry, to produce synergy effects and to reduce the selectivity of funding.

In view of the increasing globalisation of the international markets, a clear-cut competence profile is increasingly required. A performance-oriented research landscape and the development of competence centres, which enjoy worldwide recognition, the Federal Ministry for Education and Research (BMBF) sees therein the best guarantees for progress and economic success. Together with the central organisations for industry and for science, the BMBF is backing, above all, a stronger orientation of German research and development towards innovation. "Lead projects", as a new element in federal research promotion, should fulfil an important "pace-maker" function in this plan.

In technologically decisive strategic research fields, these lead projects should ensure that future-oriented, pioneering ideas are transformed more quickly into marketable products, processes and services. In order to reach the targeted goals, enterprises and universities, research institutions and users are combined to collaborate closely in networks, across sectors and disciplines. Industry and end-users are directly integrated in the research and transfer process.

There are public calls for proposals for lead projects by the BMBF, in the form of competitions for ideas. Within a given subject framework, the participants in the open competitions autonomously develop proposals for programmes of work. Independent juries of experts choose the best ideas and most promising suggested solutions in a two-step selection process. In the first step, up to 15 ideas per subject field are selected. The winners then have the possibility to elaborate their concept in detail. In this phase, further partners, in particular small and medium-sized enterprises, can apply to the winners to join their projects. Finally, the jury chooses up to five lead projects per subject field. The BMBF provides funding for the elaboration of the award-winning concepts and their later realisation. It is expected that the participants also contribute their own resources and bundle them in the project with the BMBF funding.

The subjects for the lead projects are laid down by the BMBF, in co-operation with top representatives from science and industry. In February 1997, the Ministry gave the starting signal for the first four concept competitions, and in December 1997 for a further three. Competitions were held, or are being held, in the following subject fields of special relevance to society:

- innovative products on the basis of new technologies, as well as the corresponding production processes;
- utilisation of knowledge accessible worldwide for education and further education, as well as for innovation processes;
- diagnosis and therapy by means of molecular medicine;
- mobility in conurbations;
- energy production and storage for decentralised and mobile utilisation;
- man–machine interaction in the knowledge society;
- nutrition – modern methods of food production.

4.2 – The support of small and medium-sized enterprises

The support of small and medium-sized enterprises is one focus of the Federal Government's programme of funding R&D in the business enterprise sector. The funds appropriated for this purpose in 1995 amounted to about DM1.2 billion, of which DM695 million were accounted for by indirect measures (non-technology specific). It should also be taken into account that many *Länder* governments consider funding R&D in SMEs an important component of supporting the business enterprise sector on a regional basis, for which they appropriate special funds. Finally, it should be pointed out that through the *Kreditanstalt für Wiederaufbau* (KfW; Reconstruction Loan Corporation) the Federal Government allocates more than DM1 billion every year under innovation loan programmes to financing innovations in SMEs. Since funds from the "European Recovery Programme"[1] are used for this purpose, these programmes have only relatively little impact on the federal budget.

Many new and small companies are confronted with a very specific problem: in the years prior to market launch, they do not have the necessary funds to finance high development expenditure. Hence, they depend on equity investments to implement expensive and high-risk innovation projects (see Koschatzky, 1997). The Federal Government has also responded to these needs by means of the following programmes:

- 'Direct-investment capital for young technology-based companies' (BJTU) is a pilot project, which created incentives for making equity investments in such companies. Between August 1989 and early 1995, a total of approximately DM314 million was mobilised for 336 companies.
- 'Direct-investment capital for small technology-based companies' (BTU) is a follow-up programme which provides two services: refinancing by means of the KfW, as well as co-investments by the *Deutsche Ausgleichsbank* (German Equalisation Bank) (see Kulicke, Bross and Gundrum 1997). The total equity investment volume envisaged amounts to DM900 million; in 1995, over DM120 million was mobilised.

In Germany's new *Länder*, these support programmes are complemented by a pilot project for 'New technology-based firms' (NTBFs) which offers not

1. The European Recovery Programme (ERP) is the German successor of the post-World War II Marshall plan initiative.

only funding but also consultancy services (see Pleschak and Werner, 1998). Until the end of 1995, the project had helped to establish 280 new companies and the total funding volume amounted to DM195.7 million.

5. TECHNOLOGICAL DIFFUSION AND RESEARCH LINKS

5.1 – Inter-sectoral technology flow: links between producers and users

Discussions about the importance of national innovation systems in view of the internationalisation of research and development and the globalisation of markets and corporate associations have also enlivened the debate on the characteristics of an efficient innovation system. Particular attention has been drawn in the literature to the vertical interdependences between suppliers, manufacturers and customers (von Hippel, 1988, Porter, 1990), interdependences between technologies (Kline and Rosenberg, 1986 "chainlinked technologies") and network externalities in the application of technology (see David, 1987, Arthur, 1988). In addition, emphasis has been placed on the necessity of close links between basic, applied and industrial R&D (Lundvall, 1992, Nelson, 1993, Mowery, 1992). From this viewpoint, the fundamental characteristics of modern innovation systems are the intersections of knowledge flows and the significance of spillover effects (see Amable and Boyer, 1992 and the references cited there). Spillover effects as (public) information are frequently referred to in the new theory of economic growth as a major source of endogenously generated growth. The following kinds of knowledge flows can be distinguished:

- Technological interdependences via flow of goods and services (interlinking via purchased materials and services and capital goods); in Germany empirical studies were carried out using input–output analyses (technology flow matrix) by DIW (Meyer-Krahmer and Wessels, 1989), IFO (1989) and Schumacher et al. (1995). All the formal transactions of knowledge can be subsumed here.
- Intra- and inter-sectoral flows of information (an overview can be found in Harhoff, 1991, Harhoff and König, 1993). All informal transactions can be subsumed here.

As has been shown by the analysis of the inter-sectoral linkages between the producers and recipients of technology (Meyer-Krahmer, 1992, Schumacher et al., 1995), roughly half of the accumulated know-how represented by the R&D capital stock of the Federal Republic of Germany is channelled, either directly or indirectly, into exports. For major sectors of the economy, there is a significant relationship between imports and exports on the one hand and the application of R&D on the other, although with varying degrees of intensity. About one-third of the imported know-how ultimately flows back into exports, i.e., relatively R&D-intensive foreign products are included in exports. German industry therefore has a specific strength in using high tech from abroad to be successful in foreign markets. One of the major lessons for science and technology policy is the need for open channels of transmission of technology from abroad. The second lesson is to strengthen the internal absorptive capacity of firms and research institutes as an important prerequisite of an efficient knowledge flow.

Besides the large R&D-intensive industrial sectors such as electrical engineering, chemicals, mechanical engineering and the automotive industry, significant industrial activities exist, for which know-how obtained from other sectors has greater importance than internal R&D activities. As far as the main technological flows are concerned, it can be noted that the most significant channel of diffusion in Germany predominantly follows the characteristics of the manufacturing processes (in contrast with the case of Italy in which diffusion follows the flow of materials). This underlines the importance of a diffusion-oriented technology policy in contrast to a mission-oriented technology policy, which is the dominant policy type in many OECD countries.

5.2 – Challenges to linkages within the research system: the increasing role of science-based technologies and interdisciplinarity

For several decades it has been taken for granted that publicly-financed research, in the long run at least, makes important contributions to industrial growth and competitiveness, but the request for immediate industrial exploitation of science has recently been dominating the debate in Germany. The increased pace of scientific progress and technical innovation, the increasing globalisation of the economy, and the current economic crisis have led to a public debate on the contribution science should make to industrial growth and innovations and, finally, to transforming them into marketable products. Some of the leading representatives of German industry have already argued that one should seriously consider giving up basic research in those areas where only Japanese companies can make use of the results (including large sectors of microelectronics and information technology).

Over and above this request for streamlining or closing down entire research areas, other industrial spokespersons have called for a new set of paradigms when it comes to assessing the performance of publicly-financed research institutions, such as by evaluating their actual or future use for industry (see Krull, 1994b). Demanding that in publicly-financed laboratories, researchers become more "industrially relevant" is just one side of the coin. The other is a severe attack on the principles of self-governance and autonomy, which so far have enabled scientists to pursue qualitative research in relative freedom and with a clear-cut orientation towards scientific excellence, rather than mixing various kinds of objectives and responsibilities.

It may be concluded on the basis of recent studies of emerging technologies in the US, Japan and Germany that the characteristics of technology at the beginning of the 21st century show a series of changes: drastically increasing costs of innovation; the growing significance of interdisciplinarity and the dynamism of overlapping technology areas; an increasingly close relationship between basic research and industrial application, as well as a tighter meshing of research and demand. The growing importance of multi- and interdisciplinarity is a reflection of the fact that a separation of technologies becomes more and more difficult and the overlapping areas are often highly dynamic. These phenomena have several consequences for systems of innovation. Even if not totally new, these phenomena are indications of a long-term process of structural change in knowledge production and diffusion. To an extent they may be new paradigms, with empirical evidence based on recent ISI studies, especially on the excellent studies of Grupp (1993), Grupp and Schmoch (1992), Schmoch et al. (1996a, 1996b). An investigation by ISI (Grupp and Schmoch 1992) on science-based technologies showed that technology can be clearly divided into science-based areas and less science-based ones. The science base is most distinct in the area of genetic engineering and pharmaceuticals, as well as in laser technology. A series of technology areas follow in order of sequence, albeit with a significant gap, which can, more or less, all be grouped under information technology: telecommunications, microelectronic parts, information storage and data processing, photo-telegraphy as well as measurement and sensor technology. These are followed by: optics, surface technology, organic and (only just) inorganic chemistry, as well as food technology. The authors show that the science connection diverges strongly between technological sectors but to a lesser extent between countries. This seems to be an inherent feature of technology. Internationally, high rates of growth in patenting are taking place in the science-intensive technology areas.

Internationally, the technological sub-sectors with the most dynamic development in the 1980s are more dependent on science than the others. In all probability this trend was expected to continue or intensify in the 1990s.

As Grupp and Schmoch (1992) show, in medicine and closely related areas (genetic engineering and pharmacy) and in organic chemistry, university research activities are above the anticipated value based on the science bond. In contrast, they are below average in the entire area of microelectronics and information technology research (electronics, telecommunications, information storage, data processing, photo-telegraphy). Involvement in the area of laser technology is average, as is the case in the areas of measurement technology, surface and food technology. It is clear from this that universities really do take up their intended role of protagonist in scientific technology, although the link between science and technology is much stronger in chemistry and medicine than in electrical engineering or information technology. The "microelectronics deficit" which has been much discussed recently in Germany also extends to the universities.

According to Grupp and Schmoch, the electrical industry in Germany does not seem to have succeeded as well as the chemical industry in stimulating or commissioning relevant research activities at universities. The argument of the closeness of the relationship is not only relevant for research aspects but also for the recruitment of qualified personnel as well as, in the reverse direction, the introduction of the most up-to-date insights from industrial research into academic curricula. This works more distinctly in chemistry than in electrical engineering. Based on an analysis of citations, Lieberman (1978) refers to the importance of informal networks. This shows that successful or deficient linkages between industry and universities occur over a whole range of dimensions and can be measured by a corresponding multitude of indicators.

The first consequence of the paradigms for science and technology policy underlines the relevance of a well-established area: the promotion of university/industry relationships. In this area, a long tradition of different institutional settings, financial incentives and other tools of technology transfer are used. Experience of these approaches is summarised in Table 7.3, which lists the main aims, selected effects and problems of different instruments for improving the links between universities, research institutions and industry. The instruments and institutions themselves are described extensively in Meyer-Krahmer (1990).

Institutional arrangements, such as contract research institutes or divisions, are an efficient way to link universities or public research institutes to industrial needs. A higher degree of user-orientation can be expected. The main disadvantage of this approach is the danger of the reorientation of university research from basic research to short-term, applied research. It is also necessary to avoid the danger of the educational tasks of universities being restricted by this approach. European experiences show that the establishment of applied R&D institutes as 'know-how pools' may be useful with multifunctional tasks (contract R&D, demonstrating, counselling, testing, training) in strategic technology fields. The institutions should be part of a university or closely linked to it. Co-operative research institutes solve sector-specific problems, which do not meet specific needs. In the Federal Republic of Germany, a high participation of small and medium-sized enterprises in such co-operations was observed. Recent approaches promoting national or international R&D networks are increasingly important for international competitiveness. An important precondition is a well-developed private and public R&D infrastructure.

Further discussion of the instruments displayed in Table 7.3, based on (mostly) German experiences show that tax concessions or general subsidies for extramural R&D strengthen existing internal or extramural R&D activities in industry, but have only limited effects on initiating R&D activities or corporations and start-ups. Only the reinforcement of existing R&D activities can be expected from this type of financial incentive. R&D grants for selected co-operation projects, which are combined with national strategic economic planning, are an efficient way to establish R&D capabilities and co-operation in strategic technology fields. The main problems are diverging interests of the research and business systems and ensuring flexibility for revising strategic technology planning under changed conditions. Co-operation also requires technical expertise on the industrial side. Usually extramural R&D must be accompanied by internal R&D capacity within industry.

Transfer units and innovation consultancy seem to be appropriate technology transfer instruments to activate small businesses and to adapt firms' behaviour, planning and attitude to new technology. However, problems relating particularly to the acceptance of newly established agencies may be encountered. These problems could be avoided if existing institutions with high industrial acceptance were used (hosting such new activities) instead of establishing totally new agencies. Transfer of individuals is one of the most efficient ways of technology transfer. Increasing the mobility of R&D personnel between industries, universities, research institutes and government is an important aim in many European countries. Existing barriers are often

TABLE 7.3 – Instruments to improve the links between universities, research institutes and industries

Instruments	Aims and effects	Selected problems
	Institutional arrangements	
Contract research institutes	High degree of user-orientation	Time horizon of research may be too short-term
Co-operative research institutes	High participation of SMEs	For sector specific R&D
Network approach	Establishing effective national and international R&D networks	Precondition: a well-developed private and public R&D base
	Financial incentives	
Tax reduction or subsidies for extramural R&D	Reinforcing existing internal or extramural R&D	Only small effects on initiating R&D co-operation
Subsidies for selected R&D co-operation projects	Establishing strategic technology fields	Diverging interests of research and business systems
	Technology transfer by	
Transfer units, Innovation consultancies	High participation of SMEs; initiating R&D co-operation and start-ups	Low acceptance of newly established agencies by industry and host institutions
Exchange of persons	Increasing mobility of R&D personnel	Different career structure in university and firms

Source: ISI (Meyer-Krahmer 1990).

a result of different organisational and carrier structures in the public and private sectors.

The instruments described above are mainly elements of a technology-push approach. It is well known within innovation research that demand is also an important determinant of industrial innovation and technology development. A concentration of R&D capabilities is necessary in those areas for which comparative advantages and/or high national or international demand can be expected. A national science and technology policy should not only be restricted to its own national R&D activities. Countries, acting as intelligent imitators, often use cheaper and more effective ways of technological development and industrial innovation, rather than following the first innovator strategy with high learning costs. This is true not only for small countries, but also for most countries which spend a significant proportion of their net income on R&D. Up to now, the appropriate mix of "first innovator" and "intelligent fast imitator" strategies is a very controversial issue in the S&T policy debate.

6. INTERNATIONALISATION OF R&D

Internationalisation of R&D can be classified into at least three processes (Archibugi and Michie, 1995): the international exploitation of technologies developed on a national level; the international technological collaboration of partners in more than one country for the development of know-how and innovations, whereby each partner retains his own institutional identity and ownership relationships remain unaltered; the international generation of technologies is carried out by multinational enterprises, which develop R&D strategies to create innovations across borders by building up research networks.

German corporations have also been conducting R&D abroad at a fast-growing rate as they internationalise (this section follows NIW/DIW/ISI/ZEW, 1998, p. 46). This process has not, however, uncoupled itself from the internationalisation of production. R&D spending abroad reached an estimated DM10 billion in 1995, representing 17% of all corporate R&D spending in Germany that year. The chemical and pharmaceutical industries accounted for nearly two-thirds of this amount (Table 7.4). The share of Germany's foreign R&D capability located in the US, the most important foreign research location for German firms, is quite large in relation to Germany's direct investment portfolio. German companies spent some $4 billion on R&D activities in the US in 1995. This expenditure is correspondingly reflected in the number of patent applications that German companies developed in the US. Great Britain, France and Austria are other important R&D locations for German companies. Only a few German corporations have begun to conduct research in Japan (in chemical products). Approximately 3000 foreign industrial subsidiaries operate in Germany and more than half of them conduct research and development here. These

TABLE 7.4 – R&D expenditure of German firms abroad, by product fields, 1995

Product fields	%
Chemical products	31%
Pharmaceuticals	30%
Motor vehicles	20%
Electrical engineering	3%
Machinery	3%
Aircraft	3%
Telecommunications	3%
Measurement technologies	2%
Computer technologies	1%
Medical technologies	1%
Other	3%
Total	100%

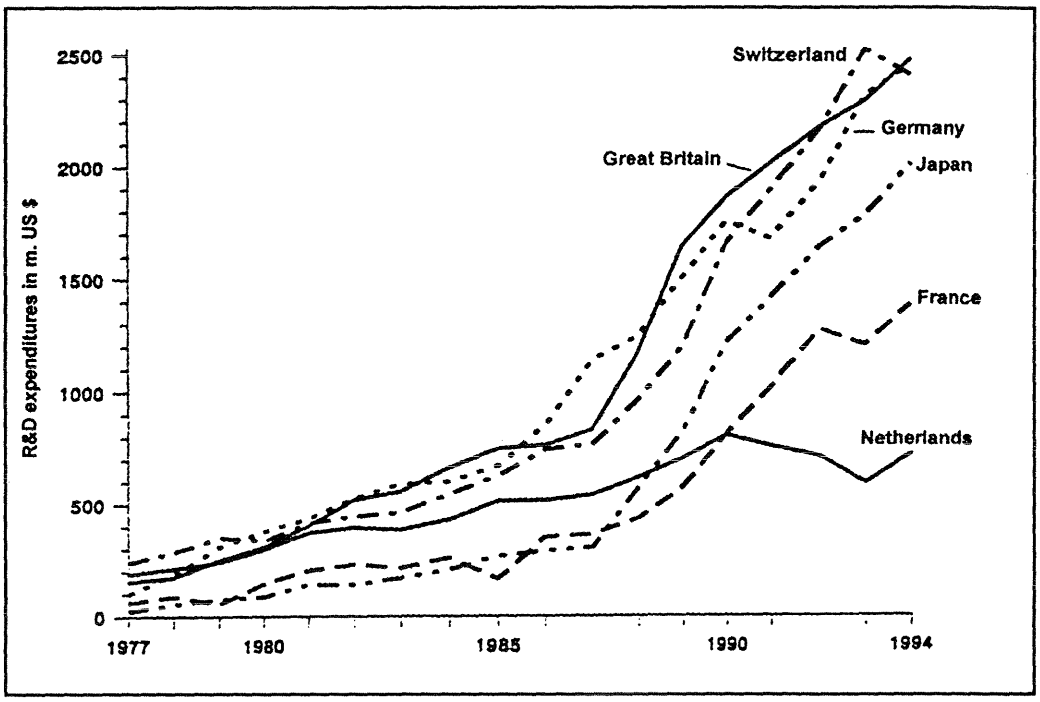
Source: NIW/DIW/ISI/ZEW (1998).

subsidiaries spent DM9.5 billion on R&D in Germany in 1995, employing some 42500 persons (half of whom came from the US, which has approximately 25% of its foreign R&D capability stationed in Germany; the other half came from Europe). This places R&D expenditure by foreign companies in Germany approximately on a par with the R&D expenditure of German companies abroad. At 15%, the foreign subsidiaries' R&D expenditure here also parallels the 16% share that their combined workforce in Germany represents out of the total industrial workforce, a figure which has remained unchanged for the past several years.

As a consequence of faster growth in overseas markets, it can be expected that successful companies, in particular, will continue to increase their overseas involvement in production and concomitantly in research and development. Germany's R&D involvement abroad is expected to grow at a faster pace than foreign-owned R&D capability in Germany.

It is evident that the US is a significant recipient of foreign R&D expenditure. Figure 7.5 illustrates that the industrialised states have continuously extended their R&D activities there. At the same time, with the exception of the Netherlands, in all the countries examined here the growth rate for the R&D expenditures increased in the second half of the 1980s. In 1994, we find Germany, Great Britain and Switzerland in the lead, followed by Japan. Preliminary data of the US Department of Commerce for the R&D expenditures of foreign enterprises for the year 1995 indicate that German

FIGURE 7.5 – R&D expenditure of foreign enterprises in the US 1977-1994



Source: Jungmittag, Meyer-Krahmer and Reger, 1999.

enterprises have yet again significantly increased their expenditure and now spend approximately $3.9 billion on R&D (just $2.5 billion in 1994). They thus have clearly the greatest R&D potential in the US, ahead of Swiss and British enterprises. The great increase in R&D expenditure by German enterprises in the US, from 1994 to 1995, is primarily explained by the boom in company takeovers, especially by important acquisitions in the pharmaceutical industry, in which the R&D capabilities also became part of the German enterprise (the following sections are based on Jungmittag, Meyer-Krahmer and Reger, 1999).

A similar picture is found when the number of independent research centres belonging to foreign enterprises in the US in the year 1994 is considered. Japan assumes the top position here, followed by Great Britain and Germany. If the technological foci of the foreign research centres are considered at the same time, it is seen that the enterprises conduct research in the US mainly in those fields in which they have their technological strengths in their home country. So the centres belonging to Japanese and Korean companies concentrate on the fields of computers and electronics. The European enterprises place their main emphasis in the sectors of chemicals, pharmaceuticals, biotechnology and new materials. Furthermore, German and Dutch enterprises perform research in the electronics sector, British companies in precision engineering, measurement and control technology, and Swedish companies in mechanical engineering.

The models of internationalisation of industrial R&D in three key technologies – pharmaceuticals, semiconductor technology and telecommunications – have been analysed in depth in a recent study carried out by ISI, DIW and ZEW (Reger, Beise and Belitz, 1999) for the BMBF. A number of results emerged from this study which advanced and complemented previous analyses and are summarised below.

The internationalisation of enterprises is more advanced in some branches than in others. Differences between sectors regarding the degree of liberalisation of international trade, the regulation of streams of direct investments, specific features of regional demand, economies of scale in production and the internationalisation of technological knowledge, result in different levels of internationalisation. The surveys in the three selected technology fields have shown that the internationalisation of R&D is mainly influenced by three factors, namely:

- early linkage of R&D activity to leading, innovative clients ('lead users') or to the 'lead market';
- early co-ordination of the enterprises' own R&D with scientific excellence and the research system;
- close links between production and R&D.

Our analysis showed that internationally active enterprises think in terms of value-added chains and process chains. Consequently, the criteria for selecting a location for R&D include not only factors of supply, such as a well-developed research infrastructure, but also demand factors, which are increasingly playing a more important part in the decisions of enterprises. Only by linking various value-added chains can (relatively) non-transferable "performance alliances" be created, establishing Germany internationally in selected fields as a location for competence centres which it would be difficult to transfer or duplicate elsewhere.

The importance of lead markets in anchoring existing industrial R&D activities and attracting new activities has increased. The market's function as a "lead market" is decisive for innovations which will become fully mature only when they come into close contact with demanding, innovative customers. In fields of technology that are strongly science-based, the results of scientific research constitute a driving force in the internationalisation of innovation processes. In both cases, regional proximity to external partners,

TABLE 7.5 – Determinants of the internationalisation of R&D in selected fields of technology

	Importance of R&D link to:	Lead market	Science/research system	Production
Pharmaceuticals	Pre-clinical research	Low	Very high	Low
	Clinical research	Very high	High	Low
Semiconductor technology	Process technology	Low	High	High
	Product development	Very high	Low	Low
Telecommunications technology	Hardware	Low	High	High
	Software	Very high	Low	Low

Source: Reger, Beise and Belitz (1999).

such as customers, competitors and scientific institutions, is an advantage. If there is a close interlinking of production and R&D activities, internationalisation of R&D follows internationalisation of production. The internationalisation of production is then the main driving force behind the internationalisation of R&D.

One central finding of this survey is that the determinants of internationalisation in the three fields of technology considered are different (Table 7.5). The dynamics of innovation concerning product development in semiconductor technology and in software telecommunications technology are largely driven by lead markets.

In process technology in semiconductor technology and in hardware for telecommunications, the linkage of production with R&D is also a significant factor. In the pharmaceutical industry a clear distinction has to be made between pre-clinical and clinical research: the innovation dynamics in pre-clinical research are driven by scientific excellence, whereas in clinical research it is the lead market that is the driving force. The link of R&D to production is very loose in this case.

It would be a fallacy to assume that national innovation policies will lose in significance as a result of globalisation. The international exploitation of innovations requires that national governments create conditions under which new technologies can be exploited within the respective countries. International technological co-operation is based on the national technological capabilities and possibilities available to the co-operation partners (Archibugi and Michie, 1995, p. 134). The international generation of innovations requires efficient national innovation policies, which meet the new challenges. This view is supported by new results obtained in innovation research, which show that, in the face of increasing international mobility on the part of enterprises and technologies, as well as the growing harmonisation of vital pre-conditions (infrastructure, human capital), efficient national innovation systems will have an increasingly significant role to play in the organisation and promotion of innovations (Porter, 1990, Lundvall, 1992 and Nelson, 1993).

7. CONCLUSIONS AND OUTLOOK

7.1 – Strengths and weaknesses of the German innovation system

Is the German innovation system still a successful model? The current picture seems still to be rather favourable, but fundamental structural and institutional changes are necessary to retain the system's long-term robustness. To cut a long story short, the German innovation system can be characterised in the following very simplified way:

- A strong role of private industry as a primary actor and a rather high proportion of industrially financed R&D with two clusters (in terms of Porter, 1990) of industrial R&D intensive sectors (mechanical engineering and the automotive industry, chemical and related industries); industry highlighting strengths in existing markets and weaknesses in new markets.
- A highly decentralised and a differentiated research system, but the institutional setting of the public research infrastructure does not fit modern modes of knowledge production; structural changes are on the top of the policy agenda instead of individual interventions on the level of research projects.
- Up to now Germany has a specific strength in "deepening" (see Ergas, 1987) further development and diffusion of key technologies compared to the US with its specific strength in "shifting" the research frontier is in many fields. The actors in the German innovation system are highly competent, but not flexible enough (no breakthroughs).
- The system is mostly manufacturing industry-based, but lacking in services. It is a growing economy but without additional jobs.
- Beside the Federal Government, the regional governments (because of their responsibility for universities and policies for small and medium-sized enterprises), local, European and public–private actors have become increasingly important.

The number of highly skilled employees is growing considerably faster than that of employees as a whole, workplaces with high qualification requirements are less subject to cutbacks than others. This creates severe scarcities of engineers and certain natural scientists on the German labour market, which is faced by a general unemployment rate of about 10%. New jobs and intensive utilisation of new technologies proceed in parallel. Innovative service companies in particular have much more favourable and, unlike industrial enterprises, positive employment expectations (see NIW/DIW/ISI/ZEW, 1998). The labour-saving effects of new technologies are unmistakable. Yet, many studies show that new technologies, as well as globalisation, primarily reduce the demand for less-qualified personnel. These persons are the real losers of technological change. Economic policy, not only S&T, has to develop new solutions, as in many OECD countries.

7.2 – Restructuring public research

An important consequence for science and technology policy is the necessary change of organisation, communication, interaction and motivation within the academic research world. The consequence for science-based technologies is the need for new ways of linking basic and applied research. Also trans- and interdisciplinarity afford better horizontal linkages between disciplines. Often in the literature the term "interdisciplinarity" is misleadingly used as a synonym for integration or for the mixing of disciplines. It is essential to understand that first-class trans- and interdisciplinary research is highly dependent on first-class disciplinary quality of the scientists involved in interdisciplinary research. Therefore, an efficient linkage between (and not the integration of) disciplines is crucial. Possible tools and mechanisms of such linkages are:

- Organisation of research: problem orientation in the case of well-definable social or industrial-technical problems. This requires, in contrast to the currently predominant internal objectives of science, new ways of project organisation and management.
- Better integration of the long-term application-oriented basic research in applied research would meet the future requirements better. This could be achieved, for example, by a better institutional network, co-operative research with specific subjects, new models of financing, improved communication and other assessment criteria.
- Team research must be strengthened besides the currently predominant orientation of academic research towards individualised research

setting. The promotion of research groups is a good beginning here, as well as the setting-up of institutes under co-operative management.

- Improved intra- and inter-sectoral mobility of researchers on an international level and also between science and industry.
- Increased flexibility of research structures: more rapid taking-up of new developments by: (i) flexibilisation of the present rigid public service rules and budget laws, (ii) deregulation of the academic administration, and (iii) networking of research institutions for a limited time, especially in an international framework ("virtual research institutes").

Applied research must be geared to a change in roles: it has not only to perform the (classic) transfer from basic research to industrial research, but also in the opposite direction, to transfer complex application problems to an attractive agenda of basic research.

A further consequence for science and technology policy relates to another traditional aspect of this area, university training. Science-based technologies as well as trans- and interdisciplinarity lead to an increasing demand for PhDs in engineering and natural sciences. This can lead to severe frictions and time-lags in the domestic educational system, which may give an incentive for firms to invest in those countries, in which such academic potential is available.

A final consequence is due to relations between industrial R&D and basic and academic R&D. In the past, government science and technology policy emphasised mainly basic and public R&D, assuming that the volume and structure of industrial and applied R&D is the responsibility of firms. The paradigms described lead to an increasing interdependence between public and industrial R&D, which may lead to the conclusion that industrial R&D cannot increase without an increase in public R&D. Up to now, there is not enough empirical evidence available to prove this. Nevertheless, it would have fundamental implications for future policy-making processes in science and technology.

7.3 – Political governance: changing roles and instruments

The changes of the context of S&T policy with growing environmental, economic and social problems, a growing systemic complexity and restricted budgets call for new ways for effective and efficient policies. The following changes in the policy-making context can be observed:

- innovation system: growing environmental, economic and social problems;
- knowledge production: trans- and interdisciplinarity, entwinement of basic and industrial research;
- policy: restricted budgets, need of effectiveness and efficiency.

Some indications exist of a change from a rational policy "decision model" (defining aims, making decisions, using well-known instruments, control of implementation), to "process organisation" (establishing visions, discussions and consensus platforms, assessing options, use of new sources of information such as technology assessment, evaluation, foresight).

Instead of "decision models" for policy-building and operation, a different model is needed which aims rather at organising societal processes to form a system of innovation to cope with the changed conditions. The German S/T system is characterised by a relatively high degree of institutional differentiation and autonomy of the major actors, one could call it a "multi-actor network" (Kuhlmann, 1998). Using evaluation procedures in such an environment is one means of creating more transparency in S&T policy. This implies an analysis of the frequently contradictory rationales of S&T policy players in order to facilitate a mutual critique and learning process. It also involves the assessment of indirect and unintended impacts of S&T policy initiatives in societal, economic and ecological spheres. This would require feedback of the knowledge gained through evaluation of the actor's networks and arenas.

In an excellent case study on interdisciplinary clinical research centres, which was deliberately designed as a policy moderation experiment, Kuhlmann (1998) shows that the underlying structure of the S&T policy arena and the present and near-future policy agenda call for advanced forms of mediated policy dialogue, and the conduct of policy evaluations producing actionable knowledge for policymakers instead of mechanistic judgements about their own performance. Ongoing analyses of the practical use of various evaluation concepts indicate that there is an important relationship between the nature of the related policy negotiation arena and the extent to which evaluation can be used as a moderation medium.

One eminent example of a new type of policy emerging from such considerations about changing policy contexts is the "BioRegio Competition". This promotional concept, announced in October 1995, also deals with a new, holistic approach to research and technology policy, which aims at integrating biotechnology capacities and scientific, economic and administrative activities. The aim is to push the commercialisation of biotechnology in

Germany, and thus create successful and also internationally acknowledged competence centres for biotechnology research and applications for the future in Germany. The object of support is the drawing-up of biotechnology development concepts, with which the regions should compete among themselves. The main focus here is the co-operation of all participants from science, industry and the public administration. Up to now this concept of pushing regional competence centres runs very successfully. It also demonstrates that the national level is no longer the dominant public player, regions as well as Europe are continuously increasing their influence. As in other European countries a new equilibrium in the division of labour between the European, national and regional levels, has to be placed on the future policy agenda.

7.4 – Internationalisation of R&D

In the context of regular reporting to the Federal Ministry of Economics on the structure of industry, a study by the HWWA – *Institut für Wirtschaftsforschung* (1995) comes to the conclusion that the globalisation of German industry (primarily with regard to production) implies a growing importance for industrial policy. With the increasing internationalisation of production, improving the quality of locations would mainly mean improving the qualification and flexibilisation of the workforce, promoting investment and accelerating public decision-making. According to this report, the financial support of domestic enterprises (i.e. enterprises with their headquarters in Germany), including the public promotion of technology, are increasingly missing the mark, since it is not certain whether these measures will generate income in national or regional locations.

An investigation by Gerybadze, Meyer-Krahmer and Reger (1997) comes to similar conclusions (for example on subsidising of R&D) with regard to this question of whether traditional technology policy is "on target" or not. However, it is precisely this circumstance which leads the authors to plead the case for a reformulated concept of technology promotion, namely: both to support national research institutions and enterprises on their path towards globalisation and, at the same time, to gain foreign research institutions and enterprises for the national innovation system and, in both cases, to attain synergy effects and spillover effects beneficial to the location. The fact that, on its own, technology policy will fall into an "inadequacy trap" under these altered circumstances needs to be emphasised again and again. Technology and innovation policy is a strategic, interdisciplinary task, and the effectiveness and success of this policy will depend, in large measure, upon whether it proves possible to establish internal networking in this field between policy areas, which have previously been fragmented.

It is decisive for the German innovation system that it should enable efficient transfer and rapid learning to take place through intelligent interlinkages, in order to pursue the strategies of the rapid second innovator, become seriously regarded as an international "player" and intelligently transfer structures, processes and framework conditions that foster innovations. This recognition brings with it a number of specific implications for technology policy, of which some examples are cited here. Some of these have already been elements of S&T policy for many years now, whereas others set new policy accents:

1. Supporting the international activities of national public R&D institutions and enterprises by: establishing international training/education and research programmes; fostering the international mobility of students and scientists as well as encouraging researchers and students from abroad to come to Germany; supporting the presence of domestic research institutions in other countries; supporting enterprises in their efforts towards a stronger global presence in R&D; building up technological competence and positioning as an international player to be taken seriously in areas which have not been among the country's classical strengths so far.
2. Supporting the location of foreign R&D establishments.
3. Two-way incentives such as promoting transnational projects; supporting the "brokerage function" of public research institutions, to support the international exchange of technology supply and demand; monitoring innovation-friendly structures in other countries and making use of this experience for national policy.

Our analysis of the innovation activity of transnational enterprises shows that they are increasingly thinking in terms of integrated process chains and lead markets, and are not primarily transferring their value-added to places which provide the best conditions for research alone (Gerybadze, Meyer-Krahmer and Reger, 1997). Market conditions obviously play an increasingly important role in R&D allocation decisions. The attractiveness of the national innovation system from this perspective is determined not so much by comparative, static competition factors such as costs and wages, as by its "dynamic efficiency".[1] This is largely dependent on the extent of social and

1. Economic theory differentiates between static efficiency – relating to one point in time – and dynamic efficiency – relating to a long-term development. It is quite possible for static and dynamic efficiency to conflict with one another.

organisational intelligence in the identification and acceptance of new structures and markets. Will complex system innovations (such as road pricing, product/service packages, closed-cycle economic concepts, new applications for information technology) be elaborated in Germany, for example, which will be used worldwide? Proactive learning through numerous field trials and pilot schemes for the identification of technical, economic, legislative and social solutions is important. Learning processes of this kind often take years. The innovation system that first succeeds in mastering these complex solutions gives participating enterprises competitive advantages, and appears more attractive to foreign investors. Candidates for such a policy approach in Germany are the fields of production, mobility, construction, health and environment.

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