GERMANY'S TECHNOLOGY DELIVERY SYSTEM

Activities and Instruments (Existing)

ACTIVITY	INSTRUMENTS

Identification: Of World-Wide, Desirable Technologies.

- Fraunhofer Gesellsehoft, FhG
- Confederation of Industrial Research Association, AIF, has 96 reasearch organizations from 34 industrial sectors
- Industry associations and trade unions are part of legislation process
- BMFT -- key technologies

Acquisition: Purchase, License, Funding, Design, Development of Identified Technologies

Technology Development

- Fraunhofer Gesellsehoft -- 40 applied research institutions, with 19 more to be established in East Germany - 1989 Budget $409 million
- Sectorial Research Cooperation -- 96 AIF organizations
- Steinbus Foundation -- 2600 employees, 114 technology transfer centers
- Europe's high-technology initiatives -- EUREKA, JESSI, etc.

Finance

- BMFT -- $471 Million for EUREKA
- Subsidies, R&D Development, investment allowances
- Key technologies
- Government participation for priority technologies

Deployment: Delivery of Available Technologies to User.

- Sectorial Research Cooperatives
- Industry & trade associations, chambers of industry & commerce, RKW
- Regional technology transfer centers
- Steinbus Foundation -- 114 technology transfer centers at local technical colleges

COUNCIL ON COMPETITIVENESS

★ ★ ★

GERMAN TECHNOLOGY POLICY:

INCENTIVE FOR INDUSTRIAL INNOVATION

By

Daniel F. Burton, Kathleen M. Hansen

An Occasional Paper

Policy Studies Series

GERMAN TECHNOLOGY POLICY:

Incentive for Industrial Innovation

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PREFACE

The United States is currently embroiled in a crucial policy debate about how to stimulate the development and application of industrial technology and thereby bolster America's competitiveness. In sorting through the policy options facing the nation, it is imperative that we understand how other countries approach this task. Along with the United States, Japan and Germany are the world's foremost industrial technology powers. And just as the United States has a unique set of policies and programs to support technology, so do Japan and Germany.

In 1991, the Council on Competitiveness published a report entitled, Japanese Technology Policy: What's the Secret? This report assessed the policies and programs that support technology development in Japan and highlighted ten key features that have contributed to its industrial competitiveness. The current paper, German Technology Policy: Incentive for Industrial Innovation, should be seen as a companion to this earlier report. The purpose is similar -- to review Germany's approach to technology development and to highlight key features that have contributed to its success. It is interesting to note, however, that many of Germany's policies and programs are quite different than those of Japan.

This paper is part of a continuing series that the Council is publishing on various aspects of the competitiveness challenge facing the United States. We hope that it will add to the perspective and understanding necessary to structure a more supportive U.S. environment for the development and application of technology.

George Fisher

George M.C. Fisher
Chairman
Council on Competitiveness
Chairman and CEO
Motorola, Inc.

EXECUTIVE SUMMARY

Germany, while drawing less scholarly and public attention than Japan, has quietly outperformed Japan by some economic measures--and has also outperformed the United States. Germany's technological innovation system clearly is a major reason why; it is a system that has excelled at making German companies world-class producers of high-quality goods.

To see a snapshot of Germany's drive toward technological excellence, look first at R&D spending. Many Americans are aware that Japan outspends the United States on non-defense R&D as a percentage of Gross National Product (GNP). But far fewer are aware that Germany also outspends the United States, investing a third again as much of its GNP in developing commercial technologies (2.6 percent compared to 1.9 percent in 1988--the most recent data available).

That investment has paid off. In 1990, Germany led the world in the export of manufactured goods. Japan exported $282 billion worth of manufactured goods that year; the United States, $287 billion; and Germany, $386 billion--28 percent more than the United States.

Germany also has outdistanced Japan and the United States in terms of the proportion of research-intensive exports. Approximately 21 percent of Germany's exports fall into that category, compared to 19.9 percent of Japan's exports and 15.5 percent of America's exports.

Germany's way of promoting industrial innovation is significantly different from that of the United States. As America seeks to strengthen its global economic competitiveness, the German system can serve as a source of ideas--ideas that, if adapted to an American context, could help maintain U.S. technological leadership.

This paper examines Germany's innovation system and reveals several key characteristics of it that help fuel that nation's economic success:

National Priority

1) Industrial innovation is a direct and specific goal of German government policy.

The straightforward German focus on industrial innovation stands in sharp contrast to U.S. public policy. The U.S. federal government does not view industrial innovation as a priority, but as the indirect result of defense spending or basic research. Therefore, while U.S. public support for industrial innovation is fragmented and unfocused, German policy encourages and supports a dense network of research institutions and industry organizations that provide complementary resources to the private sector. These resources are coordinated well enough to make them effective, but are structured flexibly enough to make them adaptable as industry's needs change. Germany's resources are at once widespread, up-to-date, and readily accessible to businesses.

Better Not First

2) Germany's innovation system focuses on doing things better rather than on doing things first.

Instead of focusing on breakthrough innovations as the U.S. system tends to do, Germany's innovation system is geared toward incremental improvements. While the United States hopes to leap far out in front of its global rivals by creating brand new technologies, Germany concentrates on creating higher-quality products and more efficient manufacturing processes for value-added production. One result of Germany's approach is that funds spent on industrial innovation are targeted toward markets that already exist and that can provide a return on the investment in the near future.

Targeted to Traditional Markets

3) Germany's innovation system concentrates on markets that have been the nation's traditional source of economic power.

Many of Germany's traditional industries have remained world leaders because new technologies and production processes have been disseminated rapidly and embraced by industry. The chemical, steel construction/mechanical engineering, and electrical engineering/fine mechanics and optics sectors represent 80% of Germany's total industrial R&D expenditures.

Industry as the Customer

4) Germany's contract research programs are driven by industry's specific technology needs.

The Fraunhofer Gesellschaft, a society that institutionalizes industry/university cooperation through its system of 38 applied research institutes, was created specifically to expedite the application of new technologies in German industry and, thereby, to improve the nation's international competitiveness. The Fraunhofer institutes are structured and funded in such a way that industry has a strong say in the kinds of research projects that are pursued. The institutes serve to extend a company's research capabilities by drawing on academic expertise. They also minimize technology transfer problems by encouraging close collaboration between academia and industry. One measure of the Fraunhofer Gesellschaft's success is that U.S. firms have become its largest supplier of foreign industry revenue.

Tailored to Different Industries' Needs

5) Germany's innovation system is tailored to the needs of individual industries.

Germany's innovation infrastructure serves different industries in different ways. For example, the priority for an industry dominated by large, self-sufficient firms--such as the German chemical industry--may be a regulatory climate that encourages R&D. By contrast, the priority for an industry consisting of many small, innovative firms--such as the German machine tool industry--may consist of ample opportunities to pool resources or exchange information.

Germany's system has been structured to serve both types of industry sectors and to provide information about cross-cutting technological developments to many different industry sectors. Smaller firms profit from information and resource sharing, thereby sustaining a competitive edge in specialized intermediate markets. Large firms benefit from the affiliation with both contract research facilities and smaller, sophisticated supplier firms.

Collaboration for Competition

6) Research cooperatives help firms resolve everyday technical problems and share information.

Most sectors of German industry have established cooperative industrial research groups to conduct joint research projects and disseminate information to industry members. An important function of these German cooperatives is to provide a way for small and medium-size companies to overcome the kinds of problems faced by their American counterparts: funding shortfalls, personnel or training gaps, and technology and equipment inadequacies. Besides using member companies' pooled funds to finance research projects of interest to the combined membership--usually on technologies that can be immediately applied--the cooperatives provide low-cost or free business counseling, training, and trend forecasting. Like the Fraunhofer Gesellschaft, the industrial research cooperatives also help define national research priorities.

Spreading the Word

7) Technology diffusion is a top priority.

Industry and trade associations, chambers of industry and commerce, and regional technology transfer and innovation centers are all part of Germany's diffusion system. Through their efforts, contacts are brokered between research partners, timely technological and business advice is rendered, facilities for technology experimentation and testing are provided, and incubators for start-up firms are funded. As a result, German companies have broad access to information about new technological developments that affect their industry.

Training, Training, Training

8) Germany's industry and professional associations excel at providing industrially relevant training.

Germany's industry associations, particularly the chambers of industry and commerce, administer training and apprenticeship programs, often in conjunction with vocational education and labor representatives, and advise businesses on further training for their workers. Germany's Fraunhofer Gesellschaft also focus students on technology issues related to industrial applications. In addition, the industry associations consult with government officials on vocational training curricula and with academia on professional curricula so that workers develop the skills most in demand. One result: German firms invest more than twice as much per year in worker training as U.S. firms do.

Private Sector Input to Public Policy

9) German industrial research cooperatives, industry groups, and trade associations help set the government's national research agenda.

Unlike in the United States where government-industry collaboration is often viewed with suspicion, German ministries are required to consult with both industry associations and trade unions when drafting legislation. The government also taps industry expertise to advise its technical agencies and even to administer some government programs and distribute some government R&D funds.

Incentives for Innovation

10) While emphasizing that the private sector must be the primary driver of industrial R&D, the German federal government leverages industrial R&D through subsidiary funds and tax incentives.

Incentives for industrial innovation include subsidies and special R&D depreciation and investment allowances. Much government support is for collaborative research involving academia, industry and trade associations. Federal funding also covers 40 percent of small and medium-size companies' R&D on key technologies and supports their technology counseling and information services. The German government also underwrites some of the participation of German firms in the European Community's high-technology initiative, EUREKA.

INTRODUCTION

Germany has aroused neither the fervor nor the fear that generally accompanies the Japanese trade debate. Nor has Germany frequently been charged with unfair trade practices. Yet Germany is a formidable international competitor with tremendous economic resources and a proud tradition of innovation and growth. Hence, a closer examination of the systems that sustain German economic innovation is both important and timely. The German model suggests practical ways of enhancing existing manufacturing technologies.

Industrial innovation in Germany is a specific goal, rather than an indirect result of defense spending or basic academic research, as it tends to be in the United States. The German innovation system is impressive in its capacity to boost industrial innovation through the rapid assimilation of new technologies. An extensive network of institutions and incentives supports the application of new technologies to existing manufacturing processes. But, although the German innovation infrastructure excels in developing German technological versatility, it is not designed to create German "technological autarky."[1] The overriding interest of German applied research facilities and industry organizations is continual refinement of existing processes for which markets are generally certain and diffusion of these innovative processes to as many firms as possible, rather than leapfrogging competitors on new technologies per se.

With this innovation system, Germany has excelled at innovation in traditional industries such as machine tools and chemicals. The chemical, steel construction/mechanical engineering, and electrical engineering/fine mechanics and optics sectors are Germany's biggest industrial investors in R&D. Together these three sectors represent more than 80 percent of that nation's total industrial R&D expenditures. Approximately two-thirds of foreign sales in 1988 in the German manufacturing industry came from the vehicle construction, electrical engineering, chemical, and mechanical engineering industries.[2] Leading German exports to the United States in 1990 were machinery and transport equipment ($17 billion), chemicals and related products ($3.13 billion), and other manufactured goods such as iron and steel and base metal products ($3.26 billion).[3]

The scale, scope, and regional character of the German innovation infrastructure contribute to a unique and dynamic innovation system. Dense networks of research institutions and industry organizations, largely structured on a regional level, provide overlapping and complementary innovation support services for a wide range of firms. These regional resources are widespread, up-to-date, and readily accessible to firms. This infrastructure is intensely involved with industrial innovation, and therefore can make a remarkable difference for German firms, and especially for smaller companies.

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*NOTE: All figures in German marks are converted to U.S. dollars at an exchange rate of DM 1.7/U.S. dollar.

The innovation infrastructure serves large firms indirectly and smaller firms more directly. The innovation-related needs and interests of firms clearly differ in relation to firm size. For instance, for the chemical industry, which is dominated by a number of large, self-sufficient firms, the establishment of favorable regulatory conditions for R&D is a higher priority than sharing information. By contrast, industries consisting of many small, innovative firms, such as the machine tool industry, depend on resource pooling and information exchange to remain competitive.*

An extensive network of industry associations and contract research facilities meets the innovative needs of both small and large firms in an effective and synergistic manner. Smaller firms benefit from the resource and information enhancement available through cooperative industrial research organizations and local association facilities. Larger firms sustain innovation through interaction with both contract research facilities and with small technologically-advanced supplier firms. The German innovation system thus effectively bridges the gaps between the technology needs of small and large firms.

Germany uses its innovation system to meet competitive challenges by concentrating on those market niches in which it has traditionally excelled. Firms have turned to flexible production and products made to customer specifications to retain market share in certain sectors. German firms stress quality and value-added production, rather than competitiveness in emerging technologies. The German innovation system thus encourages manufacturing excellence more than breakthrough innovation.

This paper focuses on the nature, scope, and effectiveness of the German innovation system. The German innovation system is considered in three parts. First, the contract and cooperative industrial research systems are examined as models for leveraging industrial research efforts through coordination between the private and public sectors. Second, the system for technology diffusion is evaluated in terms of the ways industry groups -- such as industry and trade associations, professional societies, and chambers of industry and commerce -- promote industrial innovation. Third, the federal government's policies and incentives for industrial innovation are reviewed.

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* Consider the following examples: The chemical industry association, the Verband der Chemischen Industrie (VCI), represents an industry that is quite concentrated and dominated by large and powerful firms. The chemical firms themselves provide approximately 96 percent of the funding for R&D in the sector. Technology does not diffuse far beyond the "big three" firms--Bayer, BASF, and Hoechst. The chemical industry aims to self-finance most of its R&D in order to avoid state support, which could affect the direction and structure of industrial research. The large pharmaceutical firms resist sharing even precompetitive technologies because of the tremendous expense and risks involved in their development. The activities of the VCI thus tend to be limited to regulatory involvement to influence the structural conditions for R&D. (For more detail, see Christopher S. Allen, "Political Consequences of Change: The Chemical Industry," in Peter J. Katzenstein, ed., Industry and Politics in West Germany, Ithaca,

I. CONTRACT AND COOPERATIVE INDUSTRIAL RESEARCH SYSTEMS

There are several mechanisms in Germany that provide incentives and assistance for industrial innovation. They add value to research conducted by individual firms through links to academic research and to public funding. These mechanisms encourage firms to innovate by leveraging company R&D funds and by making technological information from academia available and usable.

German firms can supplement their own technology development efforts through two primary channels: **1) Contract research facilities and 2) cooperative industrial research associations.** Contract research facilities bring academic expertise to bear on specific applied research projects for industry. The Fraunhofer Gesellschaft (FhG, or Fraunhofer Society) is the main facility for applied research in Germany. The institutes of the FhG conduct applied research for industry on a contract basis, using the facilities and personnel of regional polytechnics or technical universities.

Cooperative industrial research associations, organized according to industry sector, perform two vital functions. First, they identify, consolidate, and coordinate the research needs of member firms (generally small and medium-size enterprises, or SMEs). Second, they complete the research themselves--or they engage contract research facilities, such as those of the FhG, to complete research projects--and disseminate the results to member firms. Through the FhG and the industrial research cooperatives, industry defines German research priorities to a significant extent.

German contract and cooperative research offer five specific advantages to German firms. First, the Fraunhofer and the cooperatives encourage industrially relevant research by selecting and pursuing those projects that firms have identified as priorities. Second, the facilities encourage exchanges of information among members of the industrial and academic communities. Third, they add value to industrial research by providing commercialization assistance and business and marketing consulting. Fourth, Fraunhofer institutes help focus university students on the applied technology needs of industry. Finally, they disseminate the research results to interested parties through reports, seminars, and other documentation.

New York, Cornell University Press, 1989, p. 167.) By contrast, the association for German machine building and plant construction, the Verband Deutscher Maschinen- und Anlagenbau, or VDMA, has complex and elaborate functional and regional structures for pooling R&D efforts and sharing information. The VDMA represents an industry consisting of a number of small firms. The association closes gaps that would otherwise exist in the R&D activities and resources of member firms, in addition to engaging in more traditional political activities.

A. GERMAN CONTRACT RESEARCH AND THE FRAUNHOFER GESELLSCHAFT

The Fraunhofer Gesellschaft (FhG) is the primary vehicle for Germany's contract research system. Its mandate is to expedite the application of new technologies in German industry, thereby improving German industrial competitiveness. (See Figure 1). The FhG institutionalizes cooperation between business and academia, ensuring that university research is usable by industry. Its applied research focus distinguishes the FhG from other German research institutions such as the Max Planck Gesellschaft which focuses more on basic research. The FhG provides three services: 1) civilian contract research, 2) defense research, and 3) other services. Three-fourths of its budget is devoted to civilian contract research.

Founded in 1949, the FhG is today the most important organization for applied research in Germany, operating 40 research institutes with a combined staff of more than 6,000, one-third of whom are scientists and engineers. The activities of the various facilities are administered by the central FhG office in Munich. The FhG's administrative bodies consist of representatives from industry, academia, and government. These administrative bodies determine the research policies of the FhG, while a scientific and technical council provides guidance on the technical aspects of FhG research.

Total FhG expenditures rose by 14 percent in 1989, to $409 million (DM 696 million). This total included $47 million (DM 80 million) for investments in building and equipment, $39 million (DM 67 million) for defense research, and $323 million (DM 549 million) for contract research for industry and government (a 12 percent increase over 1988).[4] Across the FhG institutes, approximately one-half of contract research revenues come from industry, and the remainder comes from federal and state government contracts.[5] Approximately 50 percent of the FhG budget is devoted to new production technologies and microelectronics.[6]

Contracts from industry and government represent approximately 80 percent of the FhG's budget. (This general composition varies according to industry, however. Government funds are much more important for the defense-, energy-, and environment-related institutes.)[7] The federal and state governments provide funding for the FhG (in the ratio of 90:10 respectively) through matching grants. Each deutschmark that the FhG receives from industry R&D contracts is matched by 1 DM from the government.[8] Hence, the amount of public funding that the FhG receives is determined by the level of funding that the FhG receives for industry-sponsored contract research. These matching funds (known as "basic funds") furnish the remaining 20 percent of the FhG budget.[9] Basic funds are used to maintain the FhG facilities and to conduct longer-term riskier research that is not of immediate relevance to industry.[10]

Contract research in 32 of the FhG's institutes constitutes about 90 percent of the organization's research activities.[11] Project sponsors for contract research include individual firms, industry associations, government agencies, industrial research cooperatives, and industry and government agencies acting together.[12] Cooperative industrial research groups and trade and industry associations engage the FhG for research projects for smaller firms. The FhG conducts research in nine primary fields:[13]

German Fraunhofer Institutes

- GOAL

  "In concert with industry, to convert research into innovations for production and product development."

- STRUCTURE

  * 40 Institutes, 8 in manufacturing
  * 90% contract research, 10% defense
  * 6000 total personnel, 2000 scientists and engineers
  * $400 million annual funding
    – 50% from industry
    – 50% from government
    – Formal contracts for all projects
  * All Institutes sponsored by a university

- MANUFACTURING BASED INSTITUTES

  * Information Technology (KARLSRUHE)
  * Automation and Robotics (STUTTGART)
  * Flexible Manufacturing Systems (AACHEN)
  * Computer Integrated Manufacturing (STUTTGART)
  * Material Handling (DORTMUND)
  * Measurement and Sensor Technology (FREIBURG)
  * Computer Simulation and Graphics (DARMSTAD)
  * Production Technology Transfer (STUTTGART)

Figure 1

- Microelectronics
- Information technology
- Production automation and sensor technology
- Production technologies
- Materials and components
- Process engineering
- Energy technology and construction engineering
- Environmental research and health
- Technical and economic studies and technical information

For all contracts, the FhG institute concerned agrees to work on a non-profit basis according to a fixed cost ceiling. The relevant institute reports regularly to the client on research progress. All results from the contract research are kept confidential, and work products will only be made public with the consent of the contractor.[14]

Because the overhead for FhG projects can be expensive, contracts must generally be worth approximately DM 100,000 to be worthwhile for the FhG to undertake.[15] This can clearly be problematic for smaller firms that lack substantial financial resources. To overcome this disadvantage, the federal government subsidizes project costs for small German firms. Technologies that can lead to new products, components, designs, or at least to significant quality improvement, are eligible for support. The results of the technology produced are expected to be usable by industry and to meet a clear market need. These public funds generally cover about 40 to 60 percent of the total cost of the proposed project. Precise funding levels are determined according to the technical and economic risks of the proposal. The German federal government reports that in 1988, approximately 50 percent of the FhG's industrial R&D contracts came from small and medium-size companies.[16]

The FhG does accept contract research from foreign firms. Over the past five years, foreign firms have supplied 8 percent of total FhG revenues from industry. U.S. firms provided nearly 30 percent of this sum, or more than 2 percent of total FhG revenues. This makes U.S. firms the largest of the foreign industry revenue providers of the FhG.[17]

The FhG has taken an active role in some joint projects at the European Community level. For instance, it coordinates the JESSI (semiconductor technology) and PROMETHEUS (electronic traffic control systems) projects under the auspices of EUREKA. The FhG is also involved in planning for the European Flexible Automated Assembly (FAMOS) project for modernizing assembly techniques.[18]

Making Contract Research Responsive to Industrial Needs

The FhG system allows firms not only to access new production methods and technologies at relatively low cost, but also to reduce the expenses associated with the development of new technologies. Because the FhG relies on government matching funds for its spending on facilities, equipment, and risky, long-term research, the viability of the

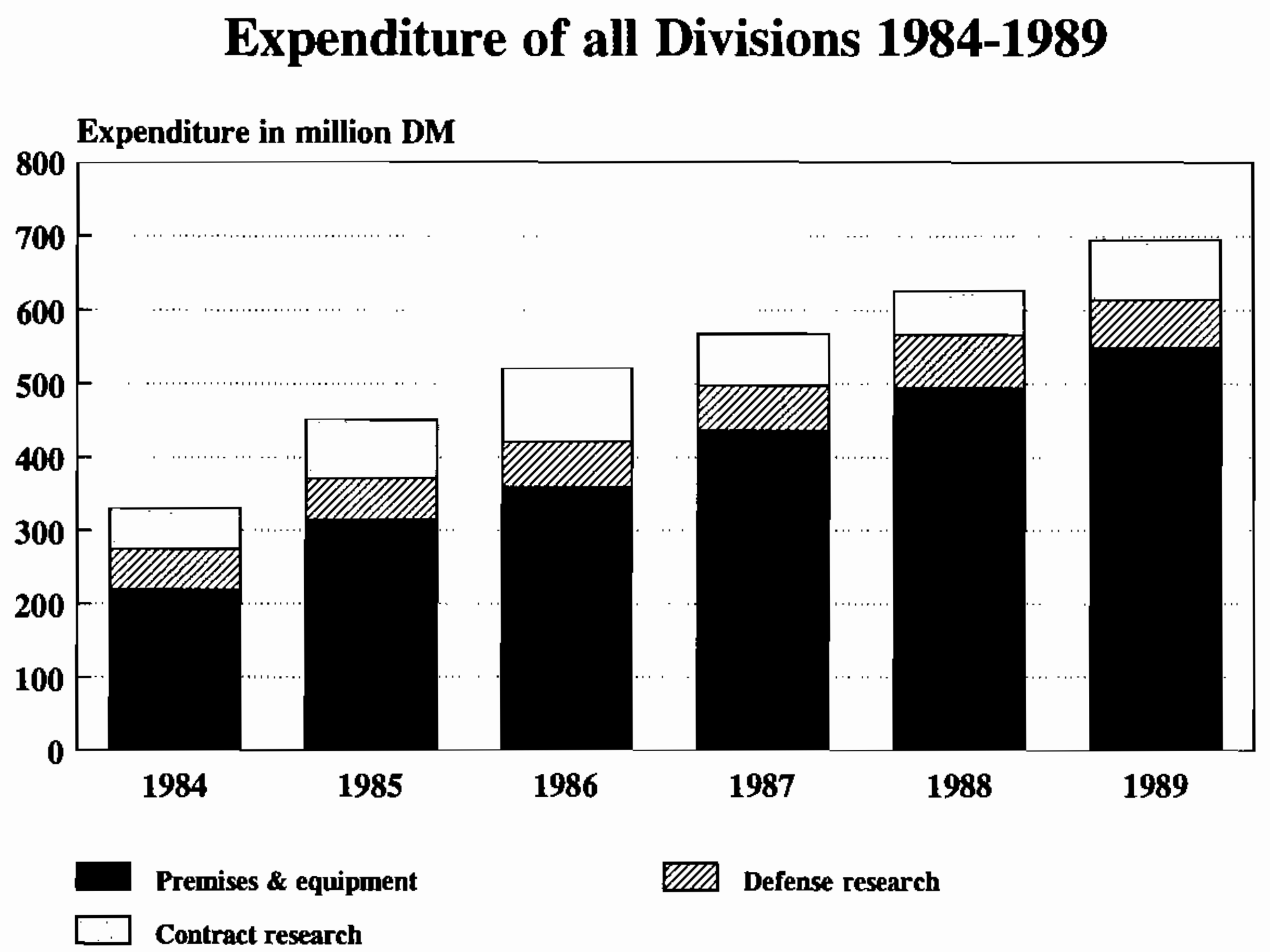

Expenditure of all Divisions 1984-1989
Expenditure in million DM
800
700
600
500
400
300
200
100
0
1984
1985
1986
1987
1988
1989
Premises & equipment
Defense research
Contract research

Figure 2

organization hinges on industrial relevance and success in the marketplace. Only research that is a priority for industry will receive public sector matching funds, because industry initiates most FhG projects. Unlike more traditional technology transfer mechanisms, the FhG research projects are designed specifically for a particular firm. Follow-up research and consultations are useful in commercializing the technologies.[19]

The structure of the Fraunhofer institutes is also sensitive to industrial research interests. A Fraunhofer institute can be established or closed in response to changing circumstances. Four conditions are vital to the establishment of a new Fraunhofer institute: 1) A clear need for the proposed research of the institute; 2) solid industrial support; 3) state government support; and 4) advocacy and leadership by a strong individual "champion."[20] An institute's structure or focus can be revised by changing the management of a particular institute or department, by bringing outside scientific research groups temporarily into existing institutes, or by collaborating with other research institutes on a specific activity. Annual turnover of up to 10 percent of the FhG scientific staff to industry facilitates FhG restructuring.[21]

The quality of the professors and directors is critical to the viability of the Fraunhofer institutes. The FhG seeks a precise mix of scientific and entrepreneurial capabilities in institute directors in order to maintain close contact with industry and to transfer products and technologies effectively. Institute directors are generally experienced managers and proven entrepreneurs, and are well-known in the academic and industrial communities.[22] In fact, some FhG institute heads serve on the boards of directors or as directors of R&D for some of the larger firms.[23] Some institutes are created around a dynamic expert and may fold if the expert leaves. The director of an institute is generally responsible for cultivating his own financial support and maintaining his own budget, which makes the selection of a director especially important.[24]

One accepted measure of the effectiveness of the FhG system in promoting industrial innovation is the amount of money it receives from industry for contract research. (See Figures 2 and 3). Income from industrial contracts has been increasing since the inception of the FhG. Both average contract volume and the number of longer-term follow-up projects increased from 1982 to 1987. Given the fact that the FhG's staff constitutes only about 1 percent of the total number of R&D personnel in Germany, the FhG's contribution to industrial innovation is quite significant.[25] Perhaps another indication of the success of the FhG is the federal government's plan to establish 19 new Fraunhofer institutes in the former East German states at a cost of approximately $235 million (DM 500 million).[26]

The FhG maintains close ties to local technical universities. Many FhG institutes are actually located on the campus of a technical university or a polytechnic, and some of the FhG institutes took over the research contracts of existing research institutes within the universities.

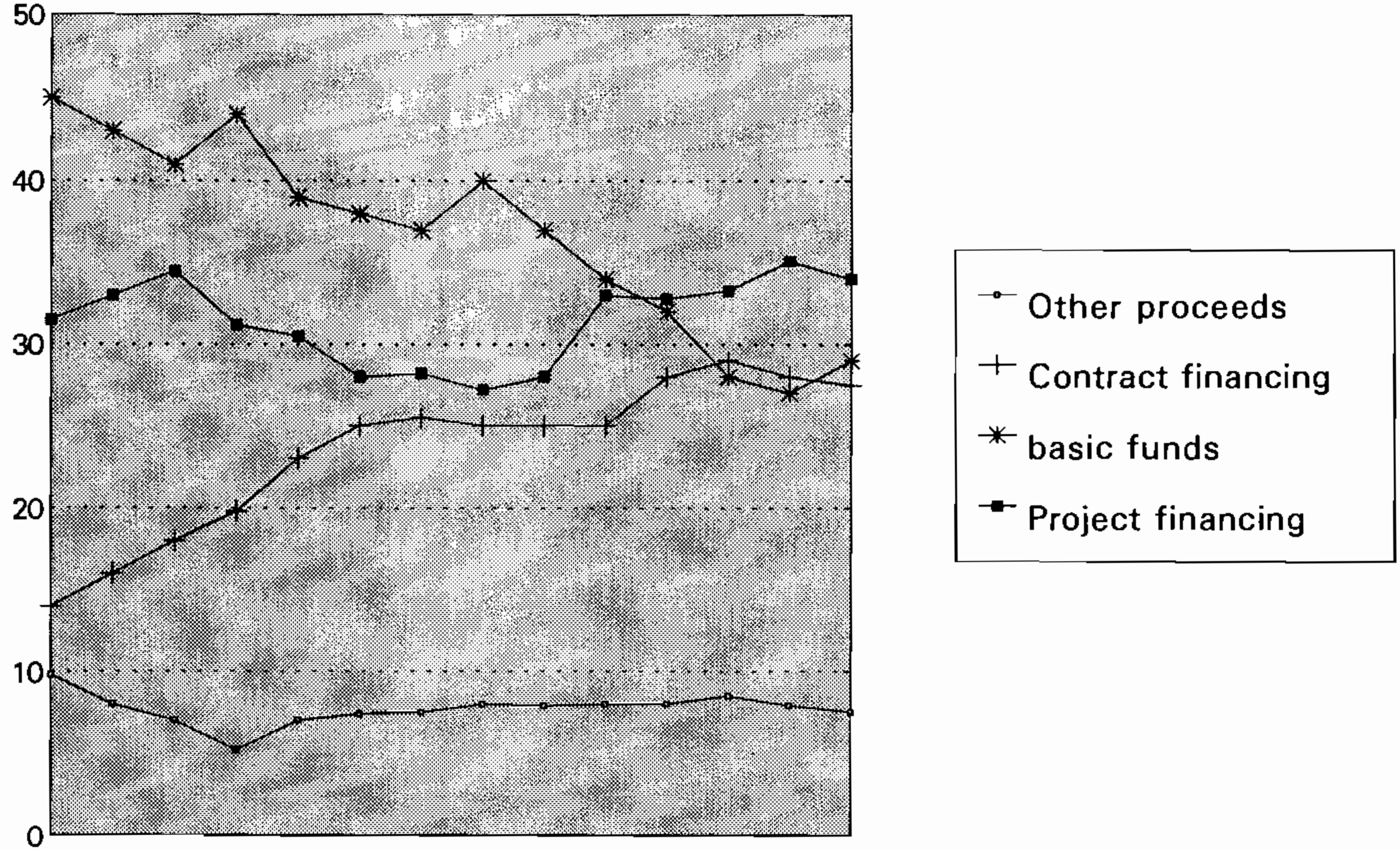
People and relationships are vital to the effectiveness of the FhG system. The transfer of technology from universities to industry is, in part, assured by the fact that directors of the FhG institutes are professors at local universities. Student employees at the institutes act as crucial links between research in the universities and practical industrial applications, because many of the students employed at the Fraunhofer Institutes go to private industry after completing their education. These ex-FhG employees are also a tremendous source of new and continuing business for the institutes.[27]

The strength of the FhG is the fact that it offers information that goes beyond the research capabilities of the firms themselves.[28] FhG projects expand upon the research conducted in industrial labs by drawing on the resources and skills of universities and polytechnics. Applied research at the FhG brings both academic and industrial resources to bear on problems of industrial innovation. The institutes of the FhG must struggle to keep this competitive edge. The FhG must simultaneously maintain sufficient scientific, staff, and organizational flexibility to address the varying needs of its industrial research contractors while engaging in enough long-term research to retain its scientific integrity and uniqueness.[29] If the FhG draws too near to the applied industrial pole of research, it risks losing its distinctive advantage vis-a-vis the laboratories of firms themselves. If its research is too fundamental and long-term, however, it will lose its relevance to industry.

Because the FhG focuses primarily on the needs of industry and some technologies (such as materials and process innovations) are more likely to get industrial support than others, research areas that are inherently long-term may not receive sufficient industrial sponsorship.[30] Either consortia or federal support may thus be more appropriate vehicles for research that is of a longer time horizon.

Relative Financing of the Division Contract Research 1976-1989

100%: DM 93 million in 1976, DM 140 million in 1979, DM 264 million in 1984, DM 549 million in 1989



Source: Fraunhofer Gesellschaft

Figure 3

THE FRAUNHOFER INSTITUTES

A comparison of two institutes of the Fraunhofer Gesellschaft demonstrates clearly the focus and direction of research in the German innovation system.[1] *Whereas institutes focusing on technologies with immediate industrial applications are flourishing, those engaged in riskier and longer-term research are encountering problems. This contrast illustrates the difficulties in garnering consistent and sufficient industrial support for risky and long-term technologies.*

The Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer-Institut für Produktionstechnik und Automatisierung, or IPA) is located in Stuttgart on the campus of Stuttgart University. The IPA conducts R&D in such fields as flexible manufacturing systems, computer-assisted manufacturing (CAM), automation of assembly and handling systems, industrial robotics and sensor technology, surface technologies, and quality engineering. The IPA has a staff of approximately 800 -- 300 full-time scientists and engineers and 500 students.

Approximately 84 percent of this institute's funding ($24 million) comes from industry. Nearly two-thirds of the IPA's contracts are from the auto industry. About 80 percent of the IPA's contracts are from larger firms (including BMW and Hewlett-Packard), and 20 percent are from smaller firms. Anecdotal evidence indicates that the IPA has been particularly active in addressing the production automation needs of smaller firms by using decentralized research and problem-solving techniques. Most IPA contracts are valued at between $71,000 and $88,000 (DM 120,000 and DM 150,000). The institute's $1.5 million (DM 2.5 million) contract for Volkswagen's logistics system is its largest.

The Fraunhofer Institute for Surface Phenomena and Bioengineering Technology (Fraunhofer-Institut für Grenzflächen und Bioverfahrenstechnik, or IGB), founded in the mid-1970s, also in Stuttgart, researches highly sophisticated technologies, including physical chemistry, biochemistry, microbiology applications for surface technologies, and medical applications such as membrane- and biotechnology.

Although the business and administrative functions of the IGB are quite similar to those of the IPA, the IGB is struggling. The situation of the IGB exemplifies the FhG's dilemma in simultaneously balancing long-term research and maximizing industrial funding. Much of the research of the IGB, albeit sophisticated, is too uncertain and too long-term to be of immediate interest and applicability to industry. Because the institute's research is not as likely to generate immediate positive outcomes for industry, firms have not been as interested in the work of the institute, and its funding has suffered. IGB staff admit that only about 20 percent of the institute's work is repeat business from industry contracts. This institute is not nearly as self-sufficient as its production engineering counterpart, which produces research results with short-term industrial applicability.

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[1] *Information in this section is drawn from the materials of the institutes themselves and from the notes of the Department of Energy team from their visit to the Fraunhofer Gesellschaft.*

B. COOPERATIVE RESEARCH[31]

Most sectors of German industry have established cooperative industrial research groups to conduct joint research projects and disseminate information from these projects to industry members. The activities of these industrial cooperatives are often directed toward small and medium-size companies. The cooperatives help these firms overcome impediments to individual R&D efforts, including funding shortfalls, personnel or training gaps, and technology and equipment inadequacies.

The approximately 100 German cooperative industrial research organizations exist in a variety of industries, including microelectronics, construction, machine building, measuring and sensor technology, metals, materials, automobile technology, coal, chemicals and biotechnology, and optics. Although cooperative industrial research has a long tradition in German industry, cooperatives in such emerging fields as ultra-precision technologies, microelectronics, and quality assurance have generally emerged only within the past 10 years. Both large and small firms are members of industrial cooperatives; membership can also include industry associations and professional societies, individual researchers, and even research institutes.[32]

Research cooperatives ensure the maintenance of an industrial focus in German applied research because their activities are guided by industrial research needs. The cooperatives collect and consolidate firms' research project proposals and evaluate them according to sector priorities. Projects of general interest to the cooperative's membership are conveyed to the appropriate research site for completion. The cooperative is generally responsible for contracting with research institutes and supervising the transfer of research results to member companies. Firms are thus spared the time and effort that would otherwise be necessary to learn about the research institutions and access the relevant research. By serving as information clearinghouses and as outreach mechanisms to research institutions, cooperative research organizations give firms incentives to coordinate their research efforts and to exchange information for mutual benefit.

Cooperative research organizations assist industry with all phases of technology development, from definition of the technical problem to assistance with funding and commercialization. Information from the cooperative research is translated quickly and broadly into industrial practice. Intermediate and final research reports are issued to the member firms. The abstracts of these reports are published later in technical periodicals. In meetings and colloquies, the member firms are informed in detail about the research findings. The research sites then often provide individual follow-up consultations for member firms.

Other sources of information for innovation are also available to members of industrial research cooperatives. For instance, each member of the cooperative for applied microelectronics (the Deutsche Forschungsgesellschaft für die Anwendung der Mikroelektronik, or DFAM) can receive one to two days of counseling, free of charge, at the cooperative's member research institutes; member firms also receive a 25 percent discount for all courses and programs at the institutes. The cooperative research groups may also forecast technology and market trends within an industrial sector. For instance, the machine building cooperative (Forschungskuratorium Maschinenbau, or FKM) offers technological prognoses for machine building and mechanical engineering, in such areas as computer-aided design and computer-assisted manufacturing (CAD/CAM), microelectronics, sensors, production planning, expert systems, and computer-integrated manufacturing (CIM).

The industrial cooperatives exert considerable influence at the policy level. Because of their expertise in the conduct and administration of industrial research programs, the cooperatives sometimes prepare (either directly or through the Federation of German Industry, the Bundesverband der Deutschen Industrie) positions and suggestions on research policy for federal, state, and European Community authorities. Others, because of their research project experience, may have input into curricula and training programs for engineers and technicians.

Truly revolutionary technologies are not likely to emerge from this cooperative system for two primary reasons. First, because the cooperatives work on a project basis according to the requests of their industry members, their focus is inherently on shorter-term, immediately applicable technologies. Firms come to the cooperatives for resolution of acute technical problems. The cooperatives have no strategic role in identifying and pursuing longer-term research projects from industry. Second, there is the problem that plagues all cooperative research organizations: firms have little incentive to share and disseminate their true breakthroughs due to intellectual property concerns.

<u>Confederation of Industrial Research Associations</u>[33]

The Confederation of Industrial Research Associations (Arbeitsgemeinschaft Industrieller Forschungsvereinigungen or AIF) is Germany's umbrella organization for cooperative industrial research groups. At present, 96 research organizations from 34 industrial sectors belong to the AIF. The AIF is a private-sector mechanism that distributes public funds for cooperative research according to industrial and technical considerations. This evaluation and distribution process ensures that public funds for industrial research are channelled according to industrial priorities. The AIF is an essential link between innovative firms, which might not otherwise have the resources to review, solicit, and obtain public R&D funds, and state officials, who might lack the technical and business experience to assess the activities and potential of grant applicants accurately.

The AIF provides two primary types of research promotion. First, it evaluates cooperative industrial research project proposals to award public research grants (available mainly through the Federal Ministry of Economics). The AIF also provides technical evaluations of project proposals and publishes the results of research conducted by AIF member organizations. Second, the AIF supports the R&D activities of individual firms by administering federal programs for this purpose and by brokering relationships between individual firms and contract research facilities. The AIF offers advice on the establishment of new industrial research associations and acts as a link between the AIF members and the public.[34] Since 1975, AIF has also administered a private-sector R&D funding system on behalf of the Foundation for the Promotion of Research in Industry.

Only about one-half of AIF-supported collective research projects are performed in institutes operated by the industrial research cooperatives themselves. The AIF is affiliated with more than 150 research institutes of universities, federal and state agencies, the Max Planck Gesellschaft, the FhG, and others, which perform research for AIF member associations. The resources of these institutes are at the disposal of AIF member organizations through the AIF's brokerage services.

The AIF issues research reports twice a year detailing the results of completed research projects. Reports on current research are also published every two months as part of the AIF Information Service on Research and Development.

II. ORGANIZING FOR TECHNOLOGY DIFFUSION

A range of industry groups expedite the dissemination of technologies (often developed at the FhG or other contract research institutes) to industry. Groups involved in technology diffusion include industry and trade associations, chambers of industry and commerce (Industrie-und-Handelskammern, or IHKs), and regional technology transfer and innovation centers. Services provided by these groups include brokerage of contacts between research partners, technology and business counseling, facilities for technology experimentation and testing, and information dissemination through publications and informal contacts. These groups accelerate industrial innovation by establishing links among firms and between industry and academia.

The German technology diffusion system thus not only spreads innovations widely throughout the economy, but also directs them to the appropriate technology users. The comprehensive range of services provided by industry organizations ensures that technologies are both available and usable for industry. As a result, industry organizations increase the efficiency of industry and reduce the costs to firms of accessing and utilizing information.

Consulting and Brokerage[35]

A number of organizations help firms innovate by providing technical and business consulting services. Industry groups that provide consulting services include private regional facilities such as the Steinbeis Foundation, chambers of industry and commerce, the Rationalization Board of German Industry (Rationalisierungskuratorium der Deutschen Wirtschaft, or RKW), industry association facilities, and university technology transfer centers.

The focus in consulting is on bringing technology to as many firms as possible and making technology practical and user-friendly. Firms can receive assistance with both technical problems and managerial issues. Industry thereby gains exposure not only to the newest practices and developments, but also to guidance on the applicability of these new technologies.

Most consulting and brokerage facilities use feasibility studies, technical audits, marketing studies, contract research and product development to promote innovation.[36] When the facility cannot resolve a technical or managerial problem itself, it can often arrange contacts with outside experts.

Other organizations act as go-betweens to set up relationships for firms interested in pursuing particular research projects. For instance, chambers of industry and commerce will arrange cooperative R&D relationships between suitable industrial partners, broker contacts between license holders and licensees, access specialized databases worldwide, and arrange partnerships between firms and research institutes. Many industry organizations and research cooperatives also operate or are affiliated with demonstration and testing facilities that provide hands-on contact with innovative products and processes.

These organizations generally stress technology dissemination and new applications of existing technologies rather than development of state-of-the-art technologies. Similarly, they emphasize the modernization of existing industries rather than encouraging new start-ups, largely because existing firms already have a technology and capital base from which to operate. Established firms generally have lower needs for capital and non-technological resources than most start-up companies.[37]

THE STEINBEIS FOUNDATION FOR ECONOMIC PROMOTION

The Steinbeis Foundation (Steinbeis Stiftung für Wirtschaftsförderung), founded in 1971 in Baden-Württemberg, provides custom research and development assistance and expert consultations on technical, organizational, and commercial matters.[2] *The Steinbeis Foundation demonstrates two important features of the German technology diffusion system: 1) the comprehensive range of innovation support services performed by this system and 2) the decentralized structure of technology development and diffusion, a structure that is responsive to the needs of local industry.*

The facilities and resources of the Steinbeis Foundation are extensive. The foundation consists of a main office in Stuttgart, 114 technology transfer centers that are often associated with local technical colleges, 16 transfer centers at technical colleges in Baden-Württemberg, and the Coordination Office for New Communication Technologies. In 1990, the Steinbeis Foundation employed approximately 2,500 people, more than 60 percent of whom were scientific and technical personnel. The total budget for the Steinbeis Foundation was approximately $41 million (DM 70 million) in 1990. More than 90 percent of the Steinbeis budget comes from contracted services to private industries and non-subsidy public sources. This fee-driven system ensures that the Steinbeis research agenda is shaped by industry.

The Steinbeis has close ties to the state government, through the Baden-Württemberg Government Commissioner for Technology Transfer who serves as chairman of the board of the Steinbeis Foundation. This tie between the state and the foundation facilitates the incorporation of industry concerns into state technology policy. The Steinbeis board consists of representatives from industry, academia, political parties, and state ministries.

The Steinbeis provides information on state-of-the-art technologies and brokers contacts between firms and research institutions. Technology advisory sessions are offered free of charge to Baden-Württemberg firms at the 114 technology transfer centers operated by the foundation. There has been strong demand from former state-owned firms in the eastern state of Saxony for these consultation services. The Steinbeis also advises local firms on technology- and research-related aid programs operated by the government of Baden-Württemberg, federal ministries, and the European Community. Steinbeis representatives assist firms in preparing and submitting applications for these programs. The Steinbeis Center for European Technology Transfer, opened on March 1, 1990, supports the involvement of small and medium-size companies in European Community research and technology programs.

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[2] *Information in this section is drawn from the Steinbeis Foundation Annual Report 1990, as well as from C. Richard Hatch, Flexible Manufacturing Networks: Cooperation for Competitiveness in a Global Economy, Washington D.C., Corporation for Enterprise Development, 1988, and from Stuart A. Rosenfeld, "Regional Development, European Style," Issues in Science and Technology, Winter 1989-1990, pp. 63-70.*

The scientific staff at the Steinbeis transfer centers conduct specific research projects for firms on a contract basis. Research results belong to the commissioning company unless the firm agrees to their publication. In 1990, the centers reported especially strong demand for R&D in the following areas: electronics and microelectronics, production automation, software engineering, environmental engineering, and sensor technology.

The Steinbeis Foundation also supports industrial innovation through its training and publications services. The Steinbeis organizes local seminars and workshops in a wide range of fields, including information technology, production automation, CAD/CAM, quality control, sensor technology, microelectronics, and management and marketing.

The Steinbeis Foundation provides a comprehensive and integrative approach to technology development. It establishes links between basic and applied research to develop new, industrially-relevant products and processes. It supplies industrial input into state research and technology policies. Baden-Württemberg firms can improve their competitiveness using Steinbeis resources--both to develop new technologies and to incorporate them effectively into business operations.

Incubators and Technology Centers [38]

Incubators (Gründerzentren) and technology centers (Technologiezentren) are regional cooperatives of newly founded firms in production-oriented sectors. They develop and market new products and processes with high market risk and high capital requirements. These facilities offer reduced-cost laboratories and equipment; consulting on funding, technical, and managerial issues; and shared administrative, conference, and exhibition facilities. They are generally operated by and affiliated with local and regional governments, regional IHKs and trade associations, technical institutes and universities, and local financial institutions. Thus, these facilities are responsive to the innovation needs of local industry.

Both incubators and technology centers help to reduce fixed costs for firms in the initial phases of technology development through the use of shared facilities and services. In addition, they offer simplified access to consulting services and to information and brokering. Association with a center lends legitimacy to start-ups and improves their chances of receiving public funds. The centers provide contacts both within the centers and with broader networks that can provide valuable funds and information.

Training[39]

Industry associations (and particularly chambers of industry and commerce) perform several vital functions with regard to training. First, they administer training and apprenticeship programs--often in conjunction with vocational education and labor representatives. (The federal government pays about half of the costs for area training centers that are operated and partly funded by chambers of industry and commerce.) Second, they advise firms on further training and vocational education for employees. Third, they consult with federal and local government officials to develop uniform vocational training and apprenticeship curricula. German industry and trade associations are generally in a better position to engage in such activities than their American counterparts, in part because German federal law requires firms to join a chamber of commerce and industry or a chamber of artisans (although industry association membership is voluntary). By contrast, the voluntary nature of U.S. trade associations makes it difficult to gather and sustain member contributions to support training programs.

Programs for vocational education, adjustment assistance, and worker training are essential to the German innovation network. Broad and integrative training programs, financed through private and public contributions, enable German workers to identify and use new technologies more effectively. Training may therefore provide impetus for further innovation by reducing worker resistance to technological change.[40] Figures from the U.S. Office of Technology Assessment suggest that German firms invest more than twice as much per year in worker training as U.S. firms invest.[41]

Trade association participation ensures that the training system suits the needs and skill requirements of industry. Many courses at local vocational education centers are designed according to industry requests. Training and education programs that are organized by trade associations are especially important to SMEs, which may lack the facilities and resources to conduct in-house training programs. The benefits of German training and education programs include higher labor productivity, lower manufacturing costs, and improved product quality.

Regulatory Activities[42]

By law, German ministries are required to consult with both industry associations and trade unions during the legislative drafting phase. Specialists from the associations have seats on the major advisory boards and experts' committees of the ministries, and they attend hearings of parliamentary committees. This consultative process means that German industry associations are generally more powerful actors in the policy-making process than their American counterparts.

Such institutionalized access also involves the industry associations more directly in the administration of public programs with industrial relevance. For instance, the Federal Ministry for Research and Technology's program for microelectronics applications was coadministered by the interested industry associations, and state subsidies were ultimately distributed by the associations rather than by the state.[43]

The Federation of German Industry, or Bundesverband der Deutschen Industrie (the umbrella organization for 34 German industry associations representing approximately 80,000 firms) and other industry associations seek to optimize the German framework for innovation and research in their regulatory activities. With this in mind, the associations gather industry input on research policy and convey industry interests to the government and to international bodies. The associations focus on intellectual property protection laws, technology, and commercial law. Some also have committees that work with small and medium-size companies to consolidate and strengthen their voices in national policymaking.[44]

German associations have credibility in the policy process to the extent that they are representative of their industries. Hence, the German associations come under some informal pressure to open and expand their membership in order to maintain their privileged access to the government. By contrast, some U.S. industry associations, which do not have such institutionalized access to the government, may tend to be more representative of larger firms or of particular interests than of an entire sector.

Participation of foreign firms in the activities of German industry associations is not generally as contentious an issue in Germany as it can be in the United States. Subsidiaries of foreign firms headquartered in Germany receive essentially national treatment. U.S. firms have access both to association membership and to informal networks. There appear to be no structural or legal hindrances to the involvement of non-German firms in associations.

However, there may be firm-specific impediments to association membership, including difficulties faced by smaller firms in generating enough resources and investment to use association membership effectively. Moreover, because there are no exact U.S. counterparts to the extensive German network of informal business relations, U.S. firms might not have the knowledge, understanding, or even the organizational ability to enter into this network system; it takes time for U.S. firms to learn the ropes. Of course, there is also some attitudinal resistance to U.S. participation, because companies are understandably reluctant to admit other potential competitors.

INNOVATION IN ACTION: THE AACHEN EXAMPLE

Perhaps the best way to understand the German innovation system is to examine it at a micro level. The innovation resources in Aachen demonstrate the importance of a comprehensive network of information and services, which include academic research risk capital, skilled labor, business consulting, and incubator facilities.[3]

The experience in Aachen suggests that innovation is not always the sole province of industry. The innovative capacity of industry is tremendously enhanced by an innovation infrastructure that leverages industry funds and activities and expedites the generation and dissemination of information.

The ***Technical University at Aachen*** *is the largest technical university in Western Europe. The university has a number of mechanisms for exchanges with industry, including contract research for long-term projects and on-site technical assistance for firms by university students. The industrial liaison office provides referrals for firms to appropriate research institutes. The university also sponsors technical breakfasts, and demonstrations and technology outreach programs for local firms. The local chamber of commerce has established a "treaty of collaboration" with the institutes of the Technical University in an attempt to institutionalize the transfer of technology from the university to industry.*

The ***Aachen Chamber of Industry and Commerce*** *(IHK) serves as a vital liaison between local firms and research institutions. For instance, the IHK operates a technology and innovation department that provides consulting services and assists with technology transfer, corporate brokering, and dissemination of information. The IHK will negotiate contracts between companies and institutes, and follow up with the firms to ensure good working relationships with the institutes. IHK staff will also assist firms with business operations such as marketing, export development, and technology assessment. In addition, the IHK issues a number of publications, including a monthly magazine on partnership options and data banks with information on new technologies.*

The mission of the ***Aachen Association for the Advancement of Innovation and Technology Transfer*** *(Aachener Gesellschaft für Innovation und Technologietransfer or AGIT) is the transfer of technology from universities to industry. It is staffed by 15 professionals with business, engineering and other technical backgrounds. Its activities include technical consulting, technology transfer, and business promotion. AGIT identifies firms' needs, matches these needs with particular research institutes, negotiates the contracts, and subcontracts to the*

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[3] *Information drawn from Best Practices in European Innovation Development, pp. 162-178 and from "A West German Incubator," Financial Times October 11, 1988.*

research institutes for specific services. AGIT also brings together smaller firms to share costs in contracting with universities. The state government of North Rhine-Westphalia funds half of the costs of the research projects AGIT manages, and industry funds the other half. AGIT also offers seminars, lectures and courses, often at the facilities of trade associations.

AGIT is the non-profit arm of the Rhineland Association for the Advancement of Innovative Entrepreneurship and Technology Transfer, Inc. This association is a holding company of local banks, insurance companies, public utilities, city and regional governments, and technical universities. The association funds about one-half of AGIT's budget, and the other half comes from the city of Aachen, the chamber of industry and commerce, and the Aachen regional economic development agency. For 1990-1992, AGIT's budget is estimated at approximately $11.8 million.

The AGIT manages the **Aachen Technology Center,** *which was established in 1984 and houses 40 to 50 high-technology start-up firms founded by Technical University graduates. The Center provides administrative services, reduced-cost laboratory space and work stations with affiliated research sites, technology and economic risk assessments, a venture capital fund, and consultations on public funding.*

The **City Savings and Loan** *of Aachen (Stadtsparkasse Aachen) maintains an innovation credit program, founded in 1983, for small, innovative firms. The heads of local firms often sit on the boards of these savings and loans, making the boards well-suited for evaluating the technical and economic potential of project proposals.*

III. THE FEDERAL GOVERNMENT FRAMEWORK FOR INNOVATION[45]

The German federal government's innovation programs contribute to industrial innovation in two ways. First, government decisions on funding priorities support the spending and research decisions of German industry and related organizations. Second, public programs enhance the viability and eompetitiveness of Germany's small and medium-size enterprises.

Four agencies have primary responsibility for federal R&D expenditures. The Federal Ministry for Research and Technology (Bundesministerium für Forschung und Technologie, or BMFT) administers more than one-half of total German R&D expenditures. Together, the Federal Ministries for Research and Technology, Education and Science (BMBW), Defense (BMVg), and Economics (BMWi) account for more than 90 percent of total federal R&D expenditures.[46] (See Figure 4.)

The federal government emphasizes that industry must be the primary driver of industrial R&D, and that the appropriate role of the government is to provide "subsidiary" funds to strengthen industrial R&D potential. The government is encouraging industry to assume an even larger share of the costs for innovation promotion. (See Figure 5.) (This is perhaps an acknowledgement of changing competitive needs and of resource constraints in the wake of German reunification.) Accordingly, Federal Ministry for Research and Technology funds for industry have dropped as a portion of total federal R&D expenditure, from 47 percent in 1982 to less than 37 percent in 1989.[47] Although overall government funding for technology and innovation promotion declined between 1982 and 1990,* indirect support for certain priority technologies (biotechnology, production engineering, information technology/microsystems, and materials research) increased substantially. The government is encouraging collaboration between science and industry. It also provides incentives for international collaboration on science and technology. Increasing public attention is devoted to technology transfer and to the promotion of small and medium-size companies.[48] The following are specific federal measures that assist industrial innovation:

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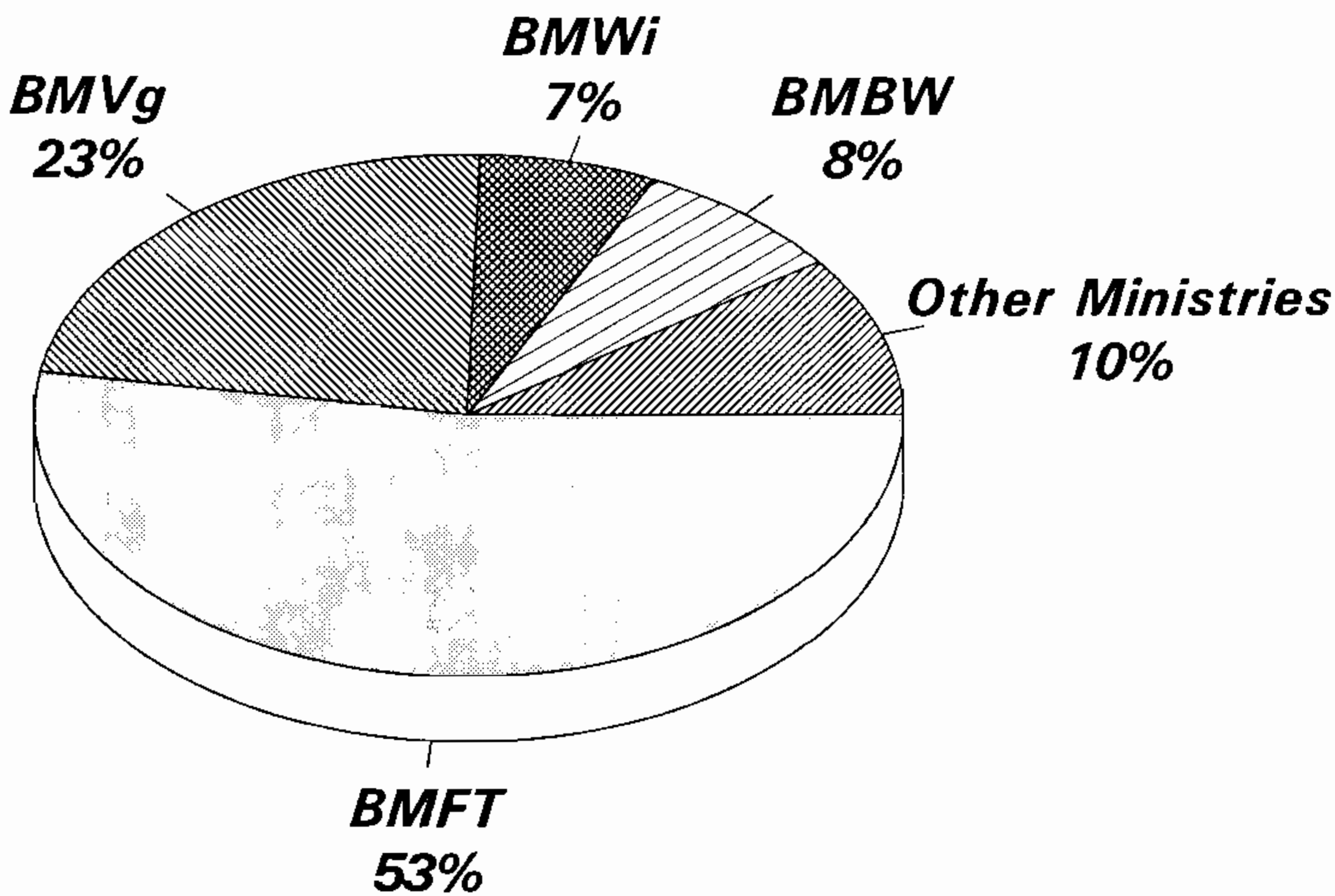
* This decline in funding should not be construed as a decline in government interest or emphasis on industrial innovation. The German federal government's efforts to increase the share of industry funding of R&D is actually a means of maximizing the industrial relevance of applied research. As observed by Steinbeis Foundation director Johann Löhn, excessive government subsidies can result in "employing the wrong people and working on the wrong projects." In fact, any Steinbeis technology center that cannot survive on fees from industrial clients is closed. For further discussion of this point, see Stuart A. Rosenfeld, "Regional Development, European Style," Issues in Science and Technology, Winter 1989-1990, p. 66.

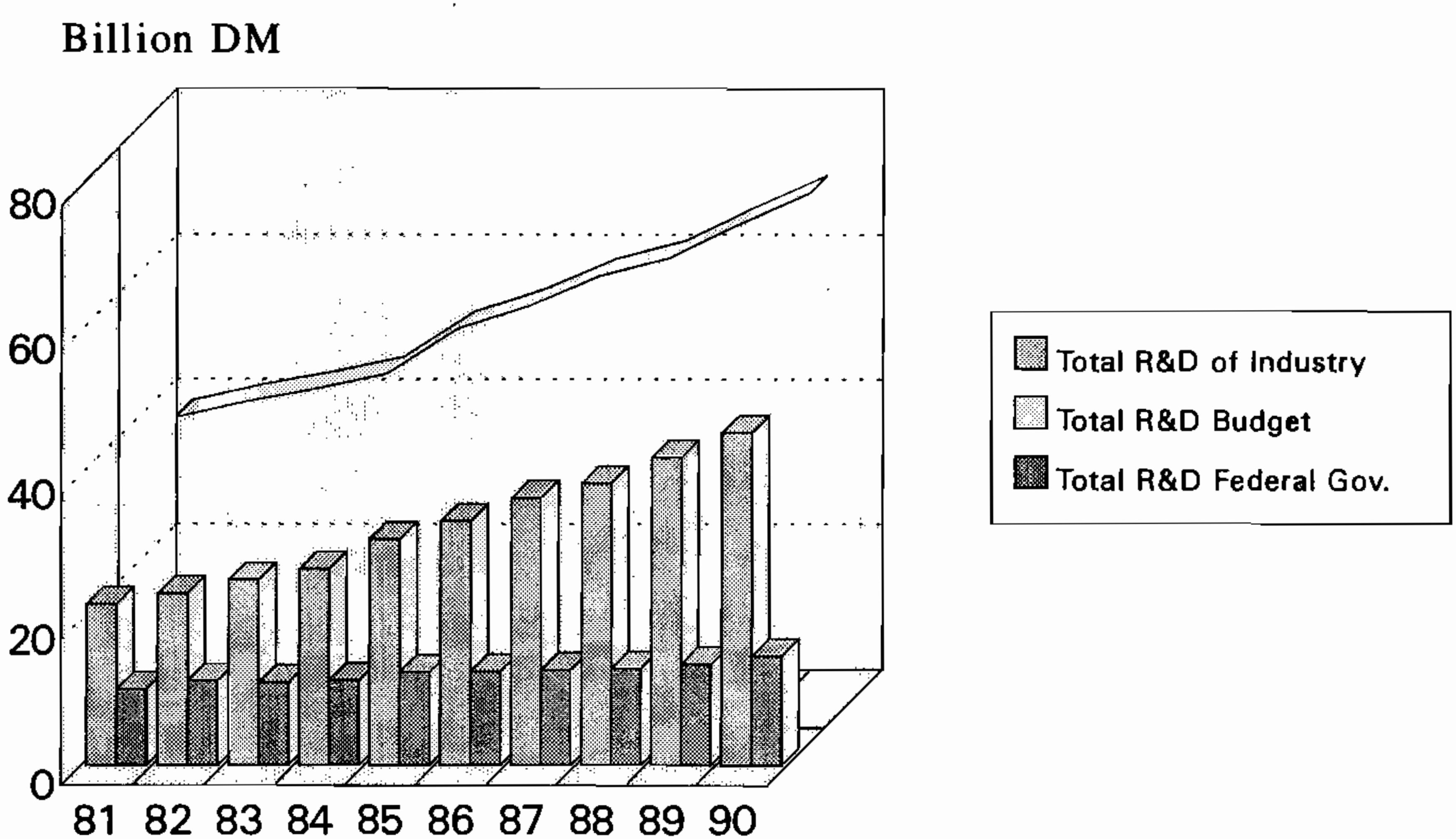
German Federal Ministries

1990 Shares of R&D Expenditures



Source: BMFT
Figure 4

R&D Budget of the Federal Republic of Germany Financed by Industry and Public Sector



Source: Fraunhofer Gesellschaft
Figure 5

General Innovation Support--The government provides a number of regulatory incentives for industrial innovation, including special R&D depreciation and investment allowances to stimulate industrial R&D. The BMFT oversees a program to promote the establishment of high-tech start-up firms by involving venture capitalists in these new firms.

Promotion of Key Technologies--The BMFT committed funds to the support of four critical technologies in 1990: biotechnology ($11 million, or DM 18 million), production engineering ($41 million, or DM 70 million), information systems/microelectronics ($18 million, or DM 31 million), and energy research ($3 million, or DM 5 million). Funding for both production engineering and information systems increased significantly over 1989--from $13 million (DM 21.5 million) to $41 million (DM 70 million) for production engineering, and from $5 million (DM 8.4 million) to $18 million (DM 31 million) for information systems. Much of the public support for these and other priority technologies, such as materials, is supplied in the form of support for collaborative research.[49]

Promotion of Cooperation Between Industry and Science--The following programs are administered through the AIF on behalf of the Federal Ministry of Economics and the Federal Ministry for Research and Technology:[50]

- **Cooperative industrial research**--The AIF reviews project proposals from member industrial research associations and funds proposals approved by the AIF experts' committee.
- **Contract R&D**--Federal funds to support industry contracts with independent research organizations are also administered by the AIF. Grants are awarded to small firms whose annual gross sales do not exceed DM 500 million ($295 million). Contract research grants generally constitute 30 to 40 percent of the contract amount, but may not exceed DM 120,000 ($70,000) per year.

Innovation Promotion in SMEs[51]--Federal funds for small business promotion rose from $200 million (DM 340 million) in 1982 to $324 million (DM 550 million) in 1990. The federal government uses several methods for promoting technology development in small business.* For instance, it will pay approximately 40 percent of their costs for pursing the key technologies

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* For German federal government purposes, a small business is considered to be one with less than DM 200 million (approximately $118 million) in gross sales or fewer than 1,000 employees. See Facts and Figures 1990, p. 100.

mentioned above.* To assist SMEs in accessing the resources and know-how of the scientific community, the government supports industrial cooperative research and contract research. As discussed above, these programs apply to both the FhG and to other research institutes. To encourage more firms to conduct R&D, the federal government allowance for the employment of new and additional R&D personnel, phased out in 1990-1991, paid up to 55 percent of the costs for additional R&D personnel, up to approximately $118,000 (DM 200,000) per year. Funds for the R&D personnel program are administered through the AIF or similar groups on behalf of the BMFT or the Federal Ministry of Economics.[52] Nearly 50 percent of small business-related project promotion has been for collaborative research, particularly in the field of mechanical engineering.[53] The government also supports technology counseling and information services for small business.

International Cooperation on Science and Technology[54]--German government involvement in R&D at the European level ranges from space technologies to production automation research. Of primary interest to industry is Germany's involvement in EUREKA, the European high-technology initiative. Four large firms in Germany-- Siemens, Bosch, IBM Deutschland, and AEG--have been particularly active in collaborating with the BMFT on research in JESSI, the microelectronics research program within EUREKA. DM 2.8 billion ($1.65 billion) of the DM 7.8 billion ($4.6 billion) cost of JESSI is covered by German firms and research institutions. German firms and research institutions participate in approximately 104 of the 297 total EUREKA projects. The BMFT supports this participation in 55 of the 104 projects with DM 800 million ($471 million) in funding.

IV. THE CHALLENGE AHEAD

Germany's success in sustaining growth and productivity demonstrates the importance of the German system as a model for innovation. Its innovation mechanisms expedite the diffusion and commercialization of new technologies. The contract research system demonstrates the potential for interaction among industry, government, and academia for mutual benefit. Resources appear to be channeled effectively according to industry needs. Small firms have

* For example, in 1988 the BMFT initiated a promotion program for computer integrated manufacturing (CIM). The BMFT covers 40 percent of the cost of development and introduction of CIM processes in firms, up to a maximum of DM 300,000 (approximately $176,000). The program covers counseling, personnel training and software change costs involved in CIM adaptation. In early 1990, the BMFT also began a program to promote microsystems (microelectronics, microoptics, etc.) that supports the development of prototypes, as well as production and commercialization. The program funds 40 percent of the costs of developing microsystems, up to a maximum of DM 400,000 ($235,000) per company. In addition, the program provides incentives for cooperative development of microsystems. For more detail on these programs, see Facts and Figures 1990, pp. 114-115.

access to contract research through the cooperative research system. The technology dissemination network helps the private sector by assisting in all phases of innovation, from technical concept to marketing and administration. The education and training systems boost industrial innovation by preparing workers who are technically proficient and adaptable to innovations. Industry concerns are expressed directly and effectively in the policy-making process.

Although the German system is very different from that of Japan and other competitor nations, it is clearly a strong framework for incremental innovation. However, the German innovation system faces two challenges. First, Germany must determine how to counter the growing manufacturing sophistication of foreign competitors. High quality at high cost--Germany's forte today--may not be not enough. Germany must match the high quality and low cost of many Asian manufacturers, especially Japan. Second, Germany may not be able to look to traditional manufacturing industries for economic growth, unless it devotes considerable attention and resources to newer cross-cutting technologies such as semiconductors and information technology that apply to a range of industrial sectors. Traditional manufacturing must be supplemented to an increasing degree by particular attention to cutting-edge technologies.

Germany's technological concerns are complicated by its tremendous economic commitments in eastern Germany and the cross-border industrial competition that will loom large after the 1992 unification of the European Community. It is unclear whether Germany's production and use of existing technologies will succeed in sustaining Germany's economic growth in the face of mounting foreign competition.

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28. Uwe Schimank, "Technology Policy and Technology Transfer from State-Financed Research Institutions to the Economy: Some German Experiences," Science and Public Policy, August 1990, p. 225.

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32. See, for instance, the brochure of the Research Community for Ultra-Precision Technology (Forschungsgemeinschaft für Ultrapräzisionstechnik), p. 8 - Membership of this cooperative includes Siemens, BASF, Bosch, SKF, individual researchers, and the Fraunhofer Institute for Production Technology.

33. Unless otherwise noted, information in this section is drawn from AIF materials, including the brochures of the AIF, "Wir fördern den Fortschritt," and the 1991 AIF Handbuch. Other information comes from Science and Technology in the Federal Republic of Germany, pp. 64-71.

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