The Academic Research Enterprise within the Industrialized Nations: Comparative Perspectives

National Academy of Sciences, National Academy of Engineering, Institute of Medicine

ISBN: 0-309-58264-4, 124 pages, 8.5 x 11, (1990)

The Academic Research Enterprise within the Industrialized Nations: Comparative Perspectives

Report of a Symposium

The Government-University-Industry Research Roundtable
National Academy of Sciences
National Academy of Engineering
Institute of Medicine
2101 Constitution Avenue, NW
Washington DC 20418

National Academy Press
Washington, D.C. March 1990

THE GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

The Government-University-Industry Research Roundtable is sponsored by the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. The Research Roundtable was created in 1984 to provide a forum where scientists, engineers, administrators, and policy-makers from government, university, and industry can meet on an ongoing basis to explore ways to improve the productivity of the nation's research enterprise. The object is to try to understand issues, to inject imaginative thought into the system, and to provide a setting for discussion and the seeking of common ground. The Roundtable does not make recommendations, nor offer specific advice. It does develop options and bring all interested parties together. The uniqueness of the Roundtable is in the breadth of its membership and in the continuity with which it can address issues.

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Library of Congress Catalog Card Number 90-60989
International Standard Book Number 0-309-04249-6

S141
Printed in the United States of America

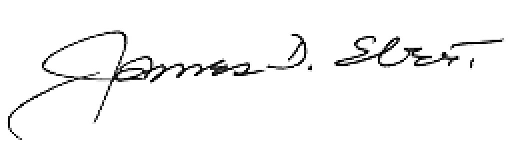
FOREWORD

National policies and programs for scientific and technological research are increasingly formulated within an international context. With the growing economic and scientific strength of European and Pacific Rim nations, research competition is intensifying. Research decisions made within any one nation rapidly influence research agendas worldwide. As a consequence, scientists, engineers, administrators, and policy-makers in government, universities, and industry require better understanding of the research systems of other nations.

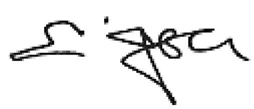
Many challenges now confront the research community worldwide. While the research agenda for scientists and engineers is expanding and ever more exciting, changes are occurring within the larger social, political, and economic environment in which research is conducted. Advances in fundamental knowledge are becoming more relevant to national economic competitiveness. Urgent global problems, such as ozone depletion and acid rain, require international collaboration in many scientific and technological fields. New communication technologies both intensify competition and allow for greater research cooperation. At the same time, however, expensive new scientific instrumentation escalates the costs of research and in several countries there is a narrowing pipeline of new scientists and engineers.

Each nation is responding to these challenges with a distinct system for organizing research activity, resulting from different histories, cultures, and traditions. With respect to the conduct of basic research, for example, the industrialized nations differ widely in the respective research roles of universities, governmental research institutes, and industrial laboratories. Furthermore, each nation has produced a unique political arrangement for the allocation of economic resources in support of research.

As the United States develops science and technology policies appropriate for the world of the 21st century, we need to understand better the historical factors which produced these diverse research systems and the social, political and economic changes now reshaping all national research capacities. We hope that the information presented within this symposium report contributes to that learning process.



JAMES D. EBERT
CHAIRMAN, GOVERNMENT-UNIVERSITY INDUSTRY RESEARCH ROUNDTABLE



ERICH BLOCH
DIRECTOR, NATIONAL SCIENCE FOUNDATION
AND
CHAIRMAN, ROUNDTABLE WORKING GROUP ON THE ACADEMIC RESEARCH ENTERPRISE

ACKNOWLEDGEMENTS

The Research Roundtable and the National Science Foundation wish to thank Mark B. Adams, James R. Bartholomew, Alan D. Beyerchen, Robert Fox, Roger L. Geiger, and Sheldon Rothblatt for their informative and candid symposium presentations. In their richly-described portrayals of decision-making throughout the past century, these six historians of science and higher education provide a necessary historical context for analyzing current trends in the research systems of the United States, Japan, the Soviet Union, Great Britain, Germany, and France.

Special thanks go to Nathan Reingold and Mary Jo Nye for chairing the symposium sessions and to T. Alexander Pond, a member of the Roundtable Working Group on the Academic Research Enterprise, for his salient commentary as a panel discussant.

Thanks also go to the staff members who organized the symposium and prepared this report, especially John P. Campbell, project director for the Roundtable Working Group on the Academic Research Enterprise, and Ronald J. Overmann, director of the NSF Program on the History and Philosophy of Science.

As conveyed in this report, the symposium discussions generated useful, sometimes controversial, insights into the worldwide prospects for university-based research in the sciences and technology. The symposium participants—speakers and guests—made an important contribution to the policy debate in the United States on the future of the U.S. academic research enterprise.

STAFF

RESEARCH ROUNDTABLE

DON I. PHILLIPS, Executive Director, Government-University-Industry Research Roundtable
JOHN P. CAMPBELL, Senior Program Officer, Roundtable Working Group on the Academic Research Enterprise
SUSAN LEVIN, Editorial Consultant
SUSAN TAWFIK, Administrative Secretary

NATIONAL SCIENCE FOUNDATION

RONALD J. OVERMANN, Program Director, History & Philosophy of Science

PREFACE

The Government-University-Industry Research Roundtable was organized in 1984 under the aegis of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. It is governed by a Council of 25 distinguished scientists, engineers, administrators, and policy-makers from government, universities, and industry. Its purpose is to create a national forum to air the issues that affect the nation's research enterprise, inject imaginative thought into understanding the issues, and explore strategies and options for improving the future of U.S. scientific research.

In 1987, the Roundtable Council inaugurated a comprehensive review of the U.S. academic research enterprise. The Council assigned this review to a Working Group of government officials, corporate executives, university administrators, and scientists. The charge to the Working Group was to examine current trends in the U.S. academic research enterprise, predict the impact of the trends on the future of the enterprise, and explore options for the future.*

To gain an international perspective on the issues addressed by the Working Group, the Research Roundtable and the National Science Foundation co-sponsored a symposium entitled “The University Research Enterprise within the Industrialized Nations: Comparative Perspectives,” held on March 23, 1989 at the National Academy of Sciences in Washington, D.C. The purposes of the symposium were to:

- Compare the histories of the larger national research systems—the United States, Japan, the Soviet Union, Great Britain, Germany, and France—with special emphasis on university research;
- Examine the current pressures placed on the research system of each nation; and
- Explore how each nation is responding to these pressures.

The symposium was organized into two panel sessions devoted to reviewing the histories of six national research systems. A morning session focused on the research systems of the relative “newcomers” to science and technology, the United States, Japan, and the Soviet Union. An afternoon session focused on the research systems of the relatively older research systems of Great Britain, Germany, and France. Panel speakers included historians of science and higher education. The panel presentations were followed by comments from discussants and other symposium guests.

Participants included senior staff within federal agencies and congressional committees, representatives from professional societies and universities, scientific advisors from national embassies, and staff from the National Academy of Sciences, National Academy of Engineering, the Institute of Medicine, and the National Research Council. An agenda for the symposium, as well as the names and affiliations of symposium participants, is found in the Appendix.

* For a discussion of the Phase One project of the Working Group on the Academic Research Enterprise, see Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues,* Washington, D.C.: National Academy Press, 1989.

This report is organized in two parts. Part One summarizes the symposium discussion regarding current challenges confronting the research systems of all nations. Part Two contains the individually-authored texts of the symposium presentations—historical perspectives on the evolution of research and higher education systems within the United States, Japan, the Soviet Union, Great Britain, Germany, and France. The text of the symposium presentation on Germany was revised in January 1990 to address challenges confronting the German research system in response to political events in Eastern Europe during 1989 and the recent momentum toward reunification of East and West Germany.

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PART ONE:

CURRENT CHALLENGES

Introduction

During the past century, the United States, Japan, the Soviet Union, Great Britain, Germany, and France substantially enlarged their research capacities to promote an accelerated pace in the generation of new knowledge. Yet each nation has pursued distinct research objectives and topics of investigation, has created a unique system for the conduct of scientific and technological research, and has adopted different methods of resource allocation.

After World War Two, significant differences arose in the role of universities within national research systems. The United States and Great Britain, for example, expanded basic research primarily within their universities as an adjunct to graduate education. In contrast, France, Germany, and the Soviet Union expanded basic and applied research capacity primarily within government research institutes. Japan developed its basic and applied research capacity primarily within industrial and governmental laboratories.

This international divergence in the research roles of universities results from many complex social, economic, and political factors unique to each nation. Variation among the countries in their involvement in wars, in their industrial and social welfare goals, and in their cultural and political traditions are reflected in their research agendas and the organization of their research systems.

At the same time, however, all research systems have evolved in interaction with those of other nations. Nations have borrowed and adapted to their own needs the organizational structures of other nations. Furthermore, contemporary science, as a process for generating new knowledge, has few geographic boundaries, especially for the mathematical, physical and biological sciences. Attempts by individual nations to promote scientific theories with idiosyncratic political, philosophical, or religious underpinnings have been generally short-lived, with detrimental consequences for the perpetrating nation.

Expectations are now increasing in all countries for research scientists and engineers to contribute to national goals. Governments and industries, for example, are seeking scientific and technological solutions to complex problems such as international economic competitiveness, health concerns, and environmental change. In those nations which have invested their basic research capacity primarily within universities, pressures for larger-scale, multidisciplinary research activity generate extraordinary challenges to the existing culture, organization, and resources of university-based scholars and their funding agencies.

While the symposium presentations and discussions reflected the diversity in national research systems and the roles of universities, they also were characterized by the recurrence of common themes. Part One of this report summarizes these themes in three categories:

- Global trends affecting all national research systems
- National responses to global trends in science and technology
- Future strategies for meeting challenges and addressing new opportunities.

Global Trends

Symposium participants identified several major trends affecting the purposes, organization, and funding of scientific and technological research within all nations. These include:

Shifting Economic Power. The post-World War Two balance of economic power is changing, with increasing competition among nations for the global marketplace. National industrial strategies promote the commercial development and marketing of research-intensive products. The growing economic strength of the European Community and Pacific Rim nations facilitates greater rates of growth in their civilian research programs compared to the United States.

Increasing Commercial Value of Basic Research. As product life cycles become shorter, advances in fundamental knowledge are increasingly relevant to commercial technology development. Nations are seeking to capture the economic benefits of basic research through stronger linkages between their basic and applied research activities. As a result, basic research priorities in many fields are increasingly tied to priorities in technology development. In those nations where academic research plays a central role within the national research system, universities are under pressure to develop stronger linkages with industry.

Continuing Military Security Concerns. Advances in fundamental knowledge are also important to development of military technology. Continuing international political tensions cause national governments to restrict the international transfer of new knowledge and technology to potential adversaries.

Improving Information Technologies. As new information technologies facilitate more rapid sharing of scientific data and analyses across national boundaries, important advances in fundamental science in one country are nearly instantaneously reported to scientists around the world. The quality of each nation's research capacity depends on the ability of its scientists to participate and cooperate in this worldwide information network.

Emerging Global Research Agendas. International cooperation is increasingly required for research into such areas as world climate change, ozone depletion, and acid rain. The scientific communities within both industrialized and developing countries are establishing cooperative research ventures to address these problems which require participation of scientists from multiple scientific fields.

Escalating Research Costs. Research programs in several fields are becoming prohibitively expensive for single nations to sponsor. The growing research capabilities and economic strength of many nations now provide new opportunities for research collaboration in those areas—such as astronomy, oceanography, high-energy physics, and space science—which require large capital investments.

National Responses

In response to these emerging global trends, policy-makers in all nations are now evaluating the roles of their research institutions—universities, government laboratories, non-profit research institutes, and industrial laboratories—and are pursuing new policies and programs. The symposium speakers described the changes occurring within each country. The following summaries focus on contemporary events; the full presentations included in Part Two describe longer-term historical developments.

United States. After World War Two, the United States achieved preeminence in most scientific and technological fields. The professional integration of U.S. scientists within worldwide scientific networks was achieved through widespread scholarly exchanges, the education of foreign students, and the introduction of new information technologies. From 1945 to 1968, U.S. basic research capacity, located primarily within its universities, greatly expanded because of increased federal funding for research and the rapid growth of higher education institutions. Since then a diversification has occurred in sources of university research support. During the 1980s, the rate of growth in non-federal funding of university research—from university, industry, and state government sources—outpaced growth rates in federal funds.

With the emerging economic and scientific strength of Japan and Europe, policy-makers in the United States are now focusing increased attention to promoting the domestic industrial utilization of the substantial U.S. basic research capacity and to sustaining a large, decentralized, and expensive research system. Characteristic of the decentralized U.S. system, responses to global economic change are occurring at all levels of government, in industries, and in universities. The allocation of federal, state, and industrial support for research now reflects a growing emphasis on programmatic research. Innovative research relationships—integrating basic and applied research programs—are emerging among industries, universities, and government agencies. University faculty in several fields are adopting entrepreneurial roles for the commercial development of their research.

Japan. Over the past several decades, Japan has created a substantially different type of research system from that which exists in the United States today. The Japanese system links basic research more closely with industry. It relies far more heavily on private financing, but with government funding in critical fields, primarily within governmental and corporate research institutes.

Japanese scientists historically have been isolated from international centers of research, despite such efforts as overseas exchange programs and journal translations. Yet throughout its history, Japan has expertly imported basic science and technology from other nations to produce and market goods more efficiently. The government has successfully targeted and subsidized the development of high-technology industries that have greatly increased the Japanese share of the international marketplace.

As Japan now achieves global economic power, the nation is turning its attention to improving the quality and quantity of its own indigenous basic research. Japanese scientists are under great pressure to become part of the worldwide network of elite scientists. Japan is in a race with Western nations to win Nobel Prizes in the sciences and is attempting to attract foreign scientists to Japanese laboratories.

Japan historically has been receptive to new arrangements for the organization of research. Although there was estrangement between universities and industry following the Second World War, cooperation between Japanese firms and universities has resumed. In this mutually beneficial relationship, companies sell or lease equipment to universities at reduced prices, professors and graduate students are given access to corporate laboratories, and faculty are appointed to lead industrial research programs funded by industry.

Soviet Union. The Soviet Union has a large number of scientists and engineers and many have made significant contributions in several scientific fields. The Soviet research system as a whole, however, is highly bureaucratic. With *glasnost',* the Soviet Academy of Sciences is pressured to reward scientific achievement and elect members based upon non-political criteria. With *perestroika,* the Soviet research system, composed primarily of large-scale institutes staffed with personnel of varying talent, is now facing increasing challenges to its organization and reward-structure. “Democratization,” however, may not necessarily present a more promising alternative for Soviet-style Big Science, which encompasses vast numbers of institutes staffed by many people who won their posts through political, Party, or personal connections. Recent attempts to administer these institutes by internal elections of all staff members have produced disorderly confusion, further politicized the Soviet research system, and hindered scientific advancement.

Given the history of the Soviet research system, universities may hold the greatest promise for Soviet science. Although beset by Party and politics after 19c30, the universities were largely left out of the vast bureaucratization that accompanied Stalinism, and they were able to remain centers of tradition and quality.

Within the Gorbachev government, there are growing pressures on the scientific enterprise to help improve the stagnant Soviet economy. Yet improving the economic contributions of Soviet science presents a profound dilemma for the Soviet government. After nearly seventy years of international near-isolation from the non-Socialist scientific community, Soviet scientists now require the use of new Western information and computer technologies and participation in worldwide scientific networks. It is uncertain whether the Soviet Union can financially or politically afford to import such technologies on a wide scale and to reinstate the international scientific exchange programs that brought Russian science to world prominence in several fields earlier in this century.

Great Britain. In response to the relative international economic decline of Great Britain over the past decades, the government has recently embarked upon a comprehensive restructuring of its research system. Emerging British research policies focus on strategic research investments, increased research productivity, and diversification in funding sources. With a stringent government science budget, research funding is being targeted to applied and strategic fields that are expected to contribute to economic growth. Projects are more closely scrutinized and selectively funded. In an attempt to make the British academic research system more efficient and productive, the Thatcher government has abolished tenure for new faculty and seeks to restrict government investments in research infrastructure to a limited number of universities.

Consistent with Thatcher government free market policies, British universities are now pressured to seek supplemental funding from non-governmental sources. Universities are forming consortia with industry as well as other universities and polytechnics to compete for limited public funding. Greater cooperation with industry in Britain is evident by the participation of industry representatives in the Universities Funding Council, the boards of research councils, and other major science advisory committees.

One the greatest challenges to the British science and research effort is the forthcoming economic integration of the European Community in 1992. At this time it is uncertain what kind of federal government may eventually emerge in Brussels and how new arrangements would affect the university-based British research system. All of the factors that go into determining science policy—taxing and funding strategies, support for industry, support for high technology, the excellence of research training, the quality of lower forms of education, the general structure of incentives and rewards for competitive achievement—may have to be reconsidered by the British government.

Federal Republic of Germany. For over one hundred years, the Germans have been committed to the proposition that competitive science and technology make economic security and its benefits possible. The key ingredient in the German research success story has not been the university system as commonly believed, but the creation of new institutions intended to stimulate or bypass those moving too slowly for the times. Competitiveness has been sustained by the turn-of-the-century institutionalization of a synergistic system for the generation and dissemination of knowledge that has functioned in a sophisticated, modern manner, blurring the distinctions between pure science, applied science and technology. In particular, there was generated a dual legitimation of basic research in organizations such as the Kaiser Wilhelm Society's network of institutes—justifying research as “pure science” when undirected and “applied” when directed, even if the same persons in the same institute were doing the work under discussion. A profound, and very useful, ambiguity allowed the government and certain far-seeing university professors to extol the virtues of the science-technology interaction when confronting industrial figures for more financial support, while stressing the distance between basic researchers and application when addressing concerns of their more culturally conservative colleagues.

After various efforts to secure economic autarky between 1914 and 1945 had failed, Germans once again became committed to a policy of highly competitive exports. The postwar West German recovery required little transformation of its basically late-19cth century economic structure, but the combination of the impact of Allied occupation and the success of earlier techniques has left West Germany the master of innovation in the sciences and technologies of the “second industrial revolution.” Efforts to construct a coherent science policy, however, were long confounded by conflicting federal claims to manage the economic implications of science and state claims to administer its educational and cultural elements. Pressures to remain export-competitive are strong, but West Germany's ability to adapt to the research environment of the “third industrial revolution”—information technologies and biotechnology—is still unclear.

Following developments in East Germany since December 1989, German science and technology policy-makers will have to focus attention to the probable integration of the research systems of East and West Germany. Since the early 1970s, the politically dominant East German institution has been the Academy of Sciences of the German Democratic Republic, which is an amalgamation of the erstwhile Prussian Academy of Sciences and the Russian model of an academy of sciences with a system of institutes. A set of councils has determined policy and personnel allocations for the Academy and the other primary research institutions such as the universities. If Article 23 of the West German Basic Law were ever invoked, allowing an East German *Land* to join the Federal Republic, then the universities and various institutes of technology that predated the segregation of the German states in 1949 would probably be readily assimilated into a unified German research system. If Article 146 were to come into play, rewriting a unified German governmental structure from the top down, the Academy system and councils would become more assimilable than otherwise.

France. For most of its post-revolutionary history, the French government did not promote scientific and engineering innovation, relying instead upon imported technology for its industry. However, beginning with the de Gaulle presidency in 1958, the government embarked upon a series of five-year plans to establish French preeminence in targeted applied research fields. The primary performers of this increased French research and development activity—including basic research—have been government research personnel, rather than university faculty who remain primarily teachers. Long-term research objectives in selected fields, such as molecular biology, have been successfully achieved within French government research institutes. French industrial support for research, however, remains small compared to that of industries in other major nations.

While French government support for university faculty research remains limited, recent educational reforms have encouraged faculty research as one means to motivate students to enter research careers. In the universities and the *grandes écoles,* which in the 1960s still tended to be set apart from the relatively prosperous world of the organizations for research, a new wave of planning has won support. The implantation of Centre National de la Recherche Scientifique (CNRS) groups in university laboratories has accelerated the diversion of significant research funding into higher education and helped further to erode the traditional French divide between research and teaching.

As France responds to a changing global economy, centralized government research planning has become even more important to the intrinsically programmatic French research system. The French government is addressing the instability of short-term planning by instituting longer-term planning cycles. While the old rivalries between the universities and the CNRS—or between the advocates of open-ended research and those with more immediate expectations of an economic return—have not completely disappeared, the benefits of thirty years of a coordinated national policy for research are evident. The pace of scientific activity is quickening, as successive governments continue to foster research in priority areas of technological innovation.

Future Strategies

All national research systems face a common set of challenges, according to the symposium discussions. How nations respond to these challenges will determine in large measure the purposes, priorities, and organization of their research systems in the 21st century. These challenges include:

Talent Renewal. The ability of each nation to sustain adequate numbers of talented scientific and engineering personnel is of paramount importance. Within some nations, a declining college-age population generates pressures to increase student interest in science and engineering. The growing ethnic diversity of some national populations generates pressures to broaden participation in scientific and technological research careers.

Rapid Adaptation. As more nations develop research capacity, rapid adaptability becomes crucial to success in scientific research. Each nation will be increasingly pressured to adjust its research priorities and programs to reflect dynamic worldwide changes in scientific fields.

Open Communication. Within the new global information environment, the unimpeded flow of scientific information will be crucial to maintaining an accelerated pace in the advancement of scientific fields. National political or economic policies that restrict such information flow will reduce that nation's ability to compete scientifically.

University Autonomy. As cooperative, applied research activity increases among university, industrial, and governmental laboratories, the continued ability of university-based investigators to explore “non-directed” research avenues becomes ever more important to scientific advancement.

Economic Relevance. As world economic competition intensifies, pressures mount to integrate research policies and priorities within broader national economic strategies. While competitive strategies may result in greater financial resources for research, these strategies may also include restrictive national collaborative research efforts among national industries, universities, and governments, as well as selective delays or prohibitions on the international dissemination of commercially strategic scientific information.

Problem Application. All nations are confronted with urgent social, health, and environmental problems. To the extent that scientific and technological research programs contribute to the solution of these problems, public support for research will continue. The expansion of research for problem-solving will most likely promote larger-scale and more multidisciplinary research organizations.

Strategic Investment. With the growing costs of research and the shifting balance of international economic and scientific strength, the ability of any one nation to maintain preeminence in all research fields is doubtful. In the future, nations may have to target for preeminence those research areas in which they have a vital strategic interest or comparative advantage, pursue collaborative international research relationships in selected fields, and import from abroad the frontier scientific or technological knowledge developed within remaining fields.

PART TWO:

HISTORICAL PERSPECTIVES

United States

THE AMERICAN UNIVERSITY AND RESEARCH

Roger L. Geiger
The Pennsylvania State University

Inventing the American University

Higher education began in this country just over 350 years ago when instruction commenced at Harvard College (1636). For the next 250 years, however, such education was largely confined to the collegiate level. The United States lacked places of higher learning that deserved to be called universities—institutions where teaching would reach the existing limits of knowledge, where future scholars could be formed, and where contributions to the advancement of knowledge would be encouraged. For the last century of this span, at least a few Americans were conscious of this lack. Benjamin Rush in 1787 called for this lacuna to be filled by a “national university”; and George Washington was sufficiently inspired by this notion to leave a bequest to this conjectural entity. Another founding father, Thomas Jefferson, dedicated his last years to designing an ambitious plan for the University of Virginia (1824). But the realities of this creation soon belied its founder's enlightened hopes. Still later, Henry Tappan made great progress in attempting to develop a university in Michigan (1852–1863). He established, among other things, an observatory and a genuine Master's Degree; but the backlash attending his efforts caused him to be fired and further progress was postponed. Before the Civil War no lasting organic connections were made between the higher learning and American collegiate education.[1]

The generation that stretched from the Civil War to 1890 was a transitional one for American higher education, which witnessed the protodevelopment of universities as well as the establishment of other new institutional forms. Numerous possibilities for linking collegiate and advanced studies were tried during these years, but none was yet able to become dominant. The first American Ph.D.s were awarded at Yale in 1861 for work done within the Sheffield Scientific School. This unit had developed in order to accommodate applied sciences and advanced studies in a separate setting where it would not disturb the pedagogy and social relations of Yale College. The following year Congress passed the Morrill Land Grant Act, which specified that agriculture and the mechanic arts would be taught in conjunction with liberal studies—in effect, the antithesis of the segregation practiced at Yale (even though Sheffield, paradoxically, was the Connecticut recipient of Land-Grant funds). In New York State the combination of philanthropy and Morrill Act funds produced in Cornell University an early prototype of the land-grant university. Utilitarian and liberal education were offered on the same level, and before long research was cultivated there as well.[2]

A more radical experiment was begun in Baltimore in the following decade. Impressed by the prestige and accomplishments of German universities, the trustees of the will of Johns Hopkins endeavored to create a German-style university in the United States, one that would for the first time institutionalize research and graduate education. The president designated to implement this design, Daniel Coit Gilman, chose only scholars as the first professors—three Americans with German Ph.D.s and three foreigners. It admitted relatively few, well prepared undergraduates, and conducted them to an advanced level of study in just a three-year course. Most of its students were post-graduates, some supported by university fellowships. Johns Hopkins University burst into a void in American higher education. Its teachers organized the disciplinary associations for history, modern languages, and economics; they also founded the major disciplinary journals in chemistry, mathematics, philology, archaeology, psychology, and modern languages. By 1889 it had conferred almost as many Ph.D.s as Harvard and Yale combined. In that time it had done more than any other institution to shape an American academic profession. But Johns Hopkins could not fill the void. It remained a small and circumscribed institution. After 1884 its available resources were devoted to establishing a medical school—an equally remarkable innovation. The university proper, however, found few means for augmenting its activities. For others, moreover, it was unclear whether or not Johns Hopkins represented the pattern of the American university. Charles W. Eliot, President of Harvard, remained skeptical: “as yet we have no university in America—only aspirants to that eminence,” he opined in 1885.[3]

Within a short time, aspirants and experiments proliferated. Both Clark (1889) and Catholic (1887) universities attempted to follow the Hopkins model, only in purer form, by opening as all graduate institutions. Stanford University (1891), on the other hand, adapted the Cornell model, which meant offering liberal, professional, and utilitarian curricula with a smattering of graduate work. In Chicago, William Rainey Harper beguiled John D. Rockefeller into bankrolling an elaborate university enterprise (1892), dedicated primarily to advancing knowledge, but also designed to bring instruction and edification to a broad slice of the population. Established institutions also experimented in search of a formula for true university work. The Columbia School of Political Science was founded by John Burgess on the assumption that the American college was outmoded. The school recruited students at the senior year of college and led them to the Ph.D. in three years of study.[4]

These different institutional innovations had different destinies. The dream of a purely graduate university at Clark under G. Stanley Hall proved ephemeral: it failed to hold the backing of its principal benefactor, nor did it win support elsewhere. It persisted as a truncated institution on the income from its initial gift. Catholic University abandoned this chimera and soon admitted undergraduates. Chicago was the most spectacular success as an institution, catapulting into the forefront of American universities. Certain of Harper's many innovations were rapidly copied—particularly summer schools and academic departments; but the University of Chicago as a whole remained an idiosyncracy, its eccentricity made possible by Rockefeller philanthropy. At Columbia, the School of Political Science reverted to the normal pattern. Instead of new departures, the evolutionary path proved in the long run most compelling.

At Harvard, Charles Eliot had experimented unsuccessfully with special graduate lectures at the beginning of his tenure. Abandoning that approach, he organized a graduate department (1873); however, since it offered no separate courses, students were still largely left on their own. Not until the success of Johns Hopkins became apparent did the inadequacy of Harvard's ad hoc arrangements force a change. The faculties of Harvard College and the Lawrence Scientific School were combined, and this new entity, Faculty of Arts and Sciences, became responsible for the reorganized Graduate School (1890). A set of courses “primarily for graduates” was now offered. For the first time, the immense resources of Harvard were organized and available for graduate work.[5]

A graduate school superimposed upon a vigorous undergraduate college had several inherent strengths. A large body of undergraduates permitted the maintenance of a numerous and specialized faculty. It was such a faculty, in turn, that made graduate education and the conduct of research possible. Moreover, it was principally the college that attracted support from American society—whether from state legislatures, alumni, or philanthropists—to finance this costly enterprise.

Graduate education in the United States remained a modest industry prior to the First World War. Some 300 Ph.D.s were graduated annually by the end of the 1890s, and that figure rose to over 400 a decade later. But undergraduate enrollments boomed after 1890, and the research universities grew even more rapidly than the system as a whole. During this era bigger was better for universities, and both public and private research universities followed this course. From 1905 to 1915 the fourteen universities that Edwin Slosson called the "Great American Universities" enrolled one of every five students in American higher education. These institutions had the resource base to sustain to varying degrees a research capacity.[6]

The characteristic American pattern that crystallized after 1890 was that of a multipurpose university which combined liberal and professional education with graduate education and research.[7] It was the size and the wealth of the enterprise as a whole that allowed these institutions to afford the critical and costly inputs to the latter activities—eminent and highly paid professors with time for research, libraries, laboratories, and other types of support. Conversely, it was the inability to afford these inputs in sufficient amounts that prevented numerous other aspiring institutions from participating meaningfully in the university research system at this time. The American university research system was thus steeply and inherently stratified. But even among successful institutions, this pattern of the American university had one serious limitation. Because most university revenues were associated with its other activities, there were few resources available for the direct costs of research *per se.* After 1900 this became an increasing problem because of the rising costs of research in the natural sciences. Previously, American universities had relied upon gifts and endowments to support their purely scientific work in separate observatories and museums, but philanthropy could not be relied upon to support the ongoing investigations within university departments. The American university prior to World War One lacked external backers for its considerable research ambitions.[8]

The Interwar Years: Emergence of a Research Economy

The most momentous change of the interwar years was the emergence of regular, recurrent sources of funding explicitly for research—a university research economy. These funds came from private sources, primarily from foundations and to a lesser extent from industry. The sums involved were not large in relation to the entire university enterprise, but their effects upon university research were profound.[9]

The great foundations of the era, essentially the repositories for major portions of the wealth of Andrew Carnegie and John D. Rockefeller, moved haltingly into the role of patrons for academic research. Immediately after the war the giant Rockefeller Foundation envisioned founding an independent research institute for the natural sciences. When the scientific community could not come to agreement about this plan, it decided instead to create a program of postdoctoral fellowships that would be administered by scientists through the National Research Council (affiliated with the National Academy of Sciences).

At the same time, the General Education Board undertook a program of assisting private colleges with matching grants for endowment. It soon became disillusioned, however, with the prospect of significantly bolstering the financial underpinnings of the nation's private sector. In 1923 several of the Rockefeller trusts embraced the mission of advancing knowledge through assistance to universities.

Beardsley Ruml, new director of the Laura Spelman Rockefeller Memorial, undertook to build knowledge of society by promoting social science research and graduate training. From 1924 to 1928 he committed $20 million to these efforts, most of which went directly or indirectly to the research universities. Almost simultaneous with the arrival of Ruml, Wickliffe Rose became head of the General Education Board and an especially created counterpart, the International Education Board. He embraced the advancement of basic science, and also focused on furthering research, for the most part within universities. Rose committed $30 million to American science before his retirement in 1929, and almost all of that flowed to the research universities.

Both Ruml and Rose sought to advance knowledge by strengthening institutions, and for that reason they concentrated their support upon the best existing science programs—"to make the peaks higher" was the apt phrase associated with Rose's approach. Their efforts consequently redounded to the benefit of the established research universities. With few staff to assist them, they parcelled out support in rather large grants to university programs that possessed their confidence. Some grants provided research capital for buildings, endowed institutes, or endowments earmarked for research-related purposes. Other large grants created multi-year support for research at a university in broadly defined areas. In such cases university scientists would themselves determine how the funds would be spent. The foundations also supported intermediary organizations like the Social Science Research Council and the National Research Council. Such funds were spread more widely through small grants-in-aid and fellowships. Only in the 1930s, when foundation assets were squeezed by the Depression, would they attempt to target their research support more narrowly through individual project grants.[10]

In the interwar period support from industry for university research was less salient (and somewhat less respectable), but it nevertheless played an important role in certain fields. Dupont exhibited the postwar spirit of cooperation with academe by establishing fellowships for graduate work in chemistry. This was the field in which ties with industry were most readily made. A number of universities with strong engineering departments established "engineering research centers" specifically to perform work for industry. Food companies and later pharmaceutical firms also turned to university scientists to investigate specific topics.[11]

For the research universities, the 1920s began in dismal fashion with high inflation and a postwar recession; but the last half of the decade brought their greatest prosperity to date. In place of a single strategy for building research capacity, two tracks emerged. For the state universities, bigger was still better. They expanded enrollments, called upon a larger contingent of graduate students to teach introductory courses, and were rewarded by their legislatures with larger appropriations. The private universities, however, faced with a shortage of capital early in the decade, restricted their enrollments and concentrated their resources. When prosperity returned, in the form of generous gifts from alumni and the foundations, they were able (again, to varying degrees) to augment substantially their investment in each of their students. This affluence allowed the hiring of eminent scholars and scientists who would carry comparatively light teaching loads.

The existence of a privately funded research economy profoundly affected the university research system. The most immediate impact of the capital grants was to create thriving pockets of research at the most favored institutions and in chosen fields. The leading private research universities gained the most, with Chicago easily topping the list. State universities received few large grants during the 1920s. The overall effect, then, was to enhance the stratification of American research universities. The funds that were distributed through the Social Science Research Council and the National Research Council were diffused more widely throughout the university community. In particular, the institution of postdoctoral fellowships made a vital contribution by firmly directing the most promising young scientists into research at the start of their academic careers. In general, foundation support for research had its intended effect in terms of institution building and in raising the stature of American science.

The indirect effects of the research economy were nevertheless also important. The stratified nature of the university research system did not seem to produce discouragement among the less favored, but rather inspired emulation. One important factor in the pattern of the American university had been changed. Research was no longer simply a fiscal burden; it was potentially a source of support as well. Foundation giving, in particular, had the effect of raising the priority of research in relation to the university's several other roles. Research and graduate education thus became ingrained aspirations of the nation's leading institutions and indelibly associated with university prestige.

As the relationship between universities, with their intramural research capacity, and the extramural research economy were developed during the interwar years, the full consequences of dependence on external funders were not yet realized. Academic science was largely directed by a tacit oligarchy of eminent scientists who shared a number of ideological convictions: university research should be supported by society because of the unforeseen benefits that basic scientific discoveries would bring; funding should be directed to the best scientists, who would produce the most fruitful results; only scientists of established reputation could determine who the best scientists might be; and, private support was preferable to that from government in order to preclude the taint of politics in these delicate decisions. During the Ruml-Rose era, it suited the purposes of the foundations to operate in a manner consistent with these values. They placed their trust in the membership of the research councils or other individual scientists in whom they had confidence. But afterward, it proved difficult to expand support for research under those conditions. An attempt to enlist industry to finance a National Research Fund, which would have been distributed by scientists, failed to elicit the needed backing. Later, during the New Deal, an attempt to induce the federal government to support university research under similar arrangements also failed. By the end of the 1930s it was becoming evident that the privately funded university research economy was not generating adequate resources for the expanding capacity of universities to perform research.

Yet there was no appreciation in the research system of how the interests of the funders of research might be accommodated with those of the performers of research.

The Postwar Era: Federal Support and Programmatic Research

Academic science demonstrated its usefulness to the country during World War Two, and it was continued usefulness that was demanded from universities by the federal government in the years following the war.[12] Prior to 1940, the only significant amounts of federal support for university research were directed to the agricultural extension stations. Afterward, this form of aid was joined by four other distinct channels to comprise the federal component of the university research economy: 1) military research continued to be supported on a broad range of subjects, with the largest amounts going toward research related to radar, fuses, and rocket propulsion; 2) the Atomic Energy Commission (AEC) assumed the mantle of the Manhattan Project, and with it control over all research involving radioactive materials; 3) the Public Health Service assumed the outstanding contracts of the wartime Committee on Medical Research and began building the National Institutes of Health (NIH) empire; and 4) last and certainly least was the implicit government responsibility to support basic university research for the advancement of knowledge. This was to be the function of Vannevar Bush's national research foundation; but, unlike the other channels, Congress failed to pass the enabling legislation during the crucial months of 1946. Instead, the Office of Naval Research (ONR), with far more funds and fewer constraints, became the patron of much basic research until the early 1950s.[13]

Quite apparent from the configuration of the 1954 university research economy (see Table 1) is the applied cast of university research, even though it was somewhat less so in 1954 than immediately after the war. Federal contract research centers claimed almost half of federal research funds, and the Department of Defense provided almost 50 percent of the funds for university research. This state of affairs was disturbing to many scientists and university leaders. Harvard's James B. Conant, for one, argued that the distinction between basic and applied research was not really the crucial issue; rather, the system had become dominated by programmatic research—“a research program aimed at a specific goal”—to the neglect of “uncommitted” or disinterested research, aimed at advancing knowledge without respect to ulterior goals.[14] The problem facing the university research system was that, while all applied research was programmatic in nature, much of the basic research being supported was as well. The principal federal supporters of basic research—NIH, AEC, and even the much-lauded ONR—all had practical missions. There seemed to be comparatively little support for the kind of unfettered investigations that had long been regarded as the true mission of the university.

The dominant presence of the federal government in the postwar research economy produced a research system that was heavily skewed toward programmatic ends. Some fields flourished, particularly physics and engineering; while in others research funds remained difficult to obtain. Funds were also lacking to “grease the wheels of science” by supporting fellowships, exchanges, meetings, and publications. Probably most serious was the absence of programs to support the strengthening of the research capacities of universities.

TABLE 1

UNIVERSITY RESEARCH ECONOMY, 1954

University Expenditures for Separately-Budgeted Research by Source of Funds ($ Millions)	
TOTAL UNIVERSITY R&D	205.5
Total Federal	141.7
Defense	101.2
HEW (largely NIH)	19.2
AEC	16.6
NSF	1.4
Other Federal	3.4
Institution/State/Local	17.5
Foundations	22.7
Industry	18.6
Private gifts & other	5.0

Not included above:	
Agriculture	74.2
Federal	13.5
State & Local	60.7
FFRDCs [20 centers]	130.0

SOURCE: National Science Foundation, *Scientific Research and Development in Colleges and Universities: Expenditures and Manpower, 1954.*

In the immediate postwar era the universities were tossed by some confusing cross-currents. The influx of students as a result of the G.I. Bill partially revitalized institutional finances after the ravages of the Great Depression and the deprivations of the war years. This forced overenrollment pushed real per-student spending figures to extremely low figures. For universities in general, the decades of the 1930s and 1940s were ones of low investment in physical capital. The 1950s brought first the uncertainties of the Korean War, accompanied by renewed inflation. Not until the mid-1950s was higher education able to benefit from a strong economy and a normal financial environment.

State and private universities were affected somewhat differently by these conditions. The research-oriented state universities expanded their budgets in order to accommodate the veterans, and then largely retained these gains as enrollments subsided. By 1955 they had considerably increased their instructional spending (and expanded their faculties). Private universities generally suffered from the diminished purchasing power of their endowment income and from a dearth of capital for improvements and additions. Voluntary support, on which they depended for capital, did not surpass the peak levels of 1928–1931 until after 1955. Improvements in research capacity prior to 1955 were made from exceedingly low levels, except perhaps at the most favored centers of research. Thus, even in the mid-1950s faculty were generally underpaid and virtually every university had a long wish list of badly needed facilities.

The situation was epitomized in the medical schools, where there was an abundance of research funding, while the schools themselves were on the brink of insolvency. This financial weakness at the institutional level, together with the concentrated nature of the research economy, combined to produce the characteristic qualities of the university research system in the postwar era.

Immediately after the war there was an intense, and not altogether healthy, competition for the services of scientists, especially atomic physicists. They naturally tended to cluster at the leading universities which offered them the most propitious conditions for research. At the same time, the continuation of wartime laboratories assured that certain fields would be dominated by the institutions at which they were located. These two factors alone were sufficient to account for the high concentration of postwar research. In fact, the concentration of research funding declined rather steadily from the postwar years to the present. (See Table 2.) In 1952, ten universities received 43.4 percent of federal research

TABLE 2

CONCENTRATION OF FUNDING

Federal R&D Obligations to Top Ten Research Universities as a Percent of Total Federal Obligations for University R&D

1952	1958	1968	1975	1987
43.4%	37.0%	27.7%	25.8%	21.9%

NOTE: Top-ten universities defined as the ten universities with largest expenditures for separately-budgeted R&D derived from federal government sources.
SOURCE: National Science Foundation

funds (not including Federally-funded Research and Development Centers [FFRDCs]); whereas their share currently is close to half that figure. Even in 1955, when FFRDCs are excluded, only perhaps six universities were expending more than $10 million on organized research—MIT, Chicago, UC Berkeley, Michigan, Illinois, and Columbia.

Agencies that supported Little Science through modest, short-term grants—ONR, NIH, and later the National Science Foundation (NSF)—distributed their funds fairly widely, even considering the concentration of research talent. Elsewhere, however, the system was characterized by quasi-permanent relationships between large university laboratories (and especially FFRDCs) and their mission-agency patrons. These latter relationships accounted for the vast bulk of funds. There was a fair degree of pluralism in the postwar research economy if one took into account the several federal patrons; however, the funding possibilities for individual fields were often quite circumscribed. The postwar statesmen of science—Bush, Conant, and Karl Compton, among others—had been concerned to preserve the pluralism of American university research by maintaining viable private alternatives to federal funding. In the natural sciences, though, just what they had feared came to pass. The overweening presence of federal support caused private foundations to withdraw from the field. In the life sciences the picture was more mixed. The foundations committed to this area were gradually overshadowed by the growth of NIH, but private funders remained and sought out unfilled niches. Only the social sciences continued to rely upon the private foundations for research funding, although the Ford Foundation came to dominate this area by the mid-1950s.

Universities responded to the expanding research economy with exasperation and apprehension, but in hindsight their adaptations reflected pragmatism and flexibility. The arrangements for accounting for organized research, which had been quite casual before the war, had to be regularized and eventually confided to a separate administrative unit. The most prominent organizational difficulty was created by the hypertrophy of research in selected areas of the university. As research became an end in itself, with its own continuing financing, the complementarily of teaching and research, upon which the academic departments were predicated, was superseded. Three kinds of adaptations were evident. In medical schools and sometimes in physics departments regular faculty positions were decoupled from departmental finances: permanent faculty were hired on “soft” money. In other areas the demands of research were often met by creating Organized Research Units [ORUs]. Such units were not new to American universities, but the extensive reliance upon them was.[15] The universities that had the largest amounts of research funding—notably MIT and Berkeley—also had the most ORUs. The federal contract research centers were a direct outgrowth of the war. For at least a decade a sorting process took place which tended to isolate some types of research in this kind of institutional quarantine (e.g. Lawrence Livermore). For a time federal funding for FFRDCs nearly equaled all federal support for university research proper, but after the 1950s they exhibited much slower growth. The dynamics of FFRDCs reflected the state of the particular fields in which they operated, as well as the prosperity of their patrons. Their relationship with their respective universities, however, was in most cases tenuous.

The Sputnik Era, 1957–1967

The transformation of the university research system began in the mid-1950s. Prosperity brought a marked expansion of the research economy: expenditures for research in universities proper grew by 60 percent from 1954 to 1958, that is, before the effects of Sputnik were felt. Increases were roughly comparable in both federal and nonfederal funding, but within the federal component two opposed tendencies were evident. Funding from the armed services became decidedly more pragmatic as military budgets came under some unaccustomed pressure. The result seems to have been greater use of FFRDCs in preference to research in universities proper. Elsewhere, funding was increased considerably by the NIH and the AEC, while the NSF finally became a significant funder of university research. With these changes the proportion of basic research in the university totals rose from 62 percent to 70 percent. The growth of research funds was greatest in the life sciences (+114 percent), reflecting the prosperity of NIH and private funders. The physical sciences also did well (+76 percent), as the AEC expanded its on-campus support. Engineering (+6 percent) reflected the armed services' preference for FFRDCs.

These years also witnessed a dramatic improvement in university research capacity, particularly at the major private institutions. In general, public research universities made greater improvements in per-student expenditures before 1955 (partly because of enrollment growth thereafter), and private universities, capitalizing on propitious financial conditions and considerably higher levels of voluntary support, generally registered their greatest increases in the decade after 1955. Because of changes in the research economy, university research became less concentrated. Whereas in 1954 only 11 universities expended more than $5 million on separately budgeted research (not including agriculture and FFRDCs) by 1958 20 institutions had crossed that threshold. The ten leading recipients of federal research funds in 1954 received 46 percent of the total (again, excluding agriculture and FFRDCs), but in 1958 their share had dropped to 37 percent. [N.B. these exclusions reflect NSF bookkeeping]

In the years prior to Sputnik, the university research system was evolving away from the cast that it had taken immediately after the war. It was encouraged in this respect by a campaign extolling the virtues of basic research that was orchestrated by NSF, and conducted by university scientists and administrators. This trend was impeded by the frugality of the Eisenhower Administration and the increasingly pragmatic orientation of the armed services. Sputnik resolved this debate in favor of basic research. Within a few years the system was transformed into the antithesis of what it had been in the postwar era.[16] The U.S. responded to Sputnik with new and substantial commitments to Space, Science, and Education. New programs in each of these areas redounded to the benefit of the research universities. The preoccupations with space resulted in the creation of NASA. Although the ultimate thrust of NASA was toward Big Science and engineering, it forged numerous links with university research during the 1960s. As a newcomer agency, eager to build a network with academic science, it was in a position analogous to ONR in the late 1940s. It provided generous funding on liberal terms to selected groups of scientists at many institutions. By 1966 NASA was supplying almost 10 percent of federal funds for academic R&D; and some 36 universities were receiving more than $1 million from the agency.

The National Defense Education Act (1958) was the beginning of regular federal support for graduate students, foreign languages and area studies. The federal government thus undertook to support the research role of universities in ways other than the funding of research.

The most spectacular gains were nevertheless made in precisely this last area. The federal government committed itself unequivocally to supporting basic research in the universities for the sake of advancing knowledge (and also besting the Soviets). From 1958 to 1968 federal funds for basic university research rose from $178 million to $1,251 million—a seven-fold increase during a decade of relatively stable prices. This was by far the most significant component of growth in an expanding research economy. Moreover, it tilted the balance of basic research into university laboratories: the national budget for basic research grew by $2,400 million during these years; university-based research accounted for $1,400 million of this increase; and federal funds comprised $1,100 million of that. Whereas universities expended 32 percent of the funds for basic research in 1958, they spent 57 percent of the total in 1968. This was a golden age for academic science. (See Table 3.)

TABLE 3

INDICATORS OF CHANGE IN UNIVERSITY RESEARCH ROLE

Year	Gross National Product ($ Mill.)	National Basic Research[1] ($ Mill.)	Percent GNP (%)	Total Univ. R&D[2] ($ Mill.)	Percent GNP (%)	Basic Univ. Research[3] ($ Mill.)	Percent Nat. Basic[4] (%)	Percent Univ. Research[5] (%)
1953	364,900	441	.12	255	.07	110	25	43
1960	506,500	1,197	.24	646	.12	433	36	67
1964	637,700	2,289	.36	1,275	.20	1,003	44	79
1968	873,400	3,296	.38	2,149	.25	1,649	50	77
1986	4,291,000	14,163	.33	10,600	.24	7,100	50	67

[1] Separately-budgeted expenditures for basic research within government, industry, universities, and non-profit laboratories.
[2] Separately-budgeted expenditures for basic research, applied research, and development within institutions of higher education, excluding FFRDCs.
[3] Separately-budgeted expenditures for basic research within institutions of higher education, excluding FFRDCs.
[4] Separately-budgeted expenditures for basic research within institutions of higher education, excluding FFRDCs, as a percent of total national basic research expenditures.
[5] Separately-budgeted expenditures for basic research within institutions of higher education, excluding FFRDCs, as a percent of total research expenditures-for basic research, applied research and development-within institutions of higher education.
SOURCE: National Science Foundation

The expansion of the research economy was accompanied by the recognition of the need to strengthen the infrastructure for university research. A report from the President's Science Advisory Committee [Seaborg Committee] recommended in 1960 that the number of research universities in the nation should be doubled—from 15–20 to 30–40.[17] The Ford Foundation had already begun a program of upgrading selected universities, and federal programs eventually followed at the principal agencies supporting university research. During the 1960s for the first time the federal government provided capital funds in substantial magnitudes to enhance the research capacity of universities. By 1968 the government was supplying almost one-third of the capital funds expended by universities—compared to a proportion of about one-eighth in the 1980s.

Federal support for infrastructural needs, together with greater financial support from other sources, rectified one of the conditions that lay behind the substantial concentration in the university research system—the restricted research capacity of all but a few institutions. The growing abundance of funds for research, especially investigator-initiated projects, ended another limitation. Finally, as the graduate schools turned out an increasing number of research-oriented Ph.D.s, the number of university researchers greatly increased. By 1968, 41 universities were receiving more than $10 million in federal R&D obligations, and the share of the total claimed by the first ten had declined to 27.7 percent.

By the mid-1960s the post-Sputnik accretions to the research economy had overgrown the configurations of the postwar-era research economy. Comparing 1958 and 1968, the additional funding to NIH and NSF, plus the net addition of NASA, comprised more than 60 percent of federal funding for university R&D. By the latter year it appeared that an “Academic Revolution” had taken place, that the values of the graduate school had gained ascendancy in American universities. The domination of investigation by disciplinary paradigms even became the object of criticism: a crisis of “relevance” was perceived in the university curriculum, and perhaps in the conduct of research itself. Meanwhile, much of the programmatic research sponsored by the Department of Defense was deemed unfit for university campuses.

The “new” federal funds in the research economy were spread far more widely than the “old” funds had been, thereby furthering the decentralization of the research system. This, in turn, enhanced competition. University leaders and academic scientists greeted the new regime with alacrity. The emphasis given to basic research allowed them to do what they felt universities ought to be doing, and without the misgivings about secrecy, continuity, or external control that had plagued them during the preceding era. Thus, universities readily adapted by increasing their emphasis on research and its attendant values. This meant aggressively recruiting productive scholars and scientists, and devoting their own discretionary funds to building research capacity. This was the rational course. For perhaps the first time in university history, research seemed to be a remunerative activity for a substantial number of institutions. Not only did the federal government stand ready to assist universities to meet the high overhead expenses associated with efforts to maintain and extend research capacity, but that capacity could now assuredly generate a continuing flow of project funds and indirect-cost reimbursements.

In this heady environment, few expressed real concern over the attenuation of pluralism. The Seaborg Committee had pronounced that the federal government, and only the federal government, was responsible for expanding the system of university research. During the 1960s each discipline in turn defined its absolutely indispensable research needs, and then, in effect, presented the bill to the public.[18] The federal contribution to academic R&D rose from 53 percent in 1953, to 63 percent in 1960, to a peak of 74 percent in 1966; and remained above 70 percent for the remainder of the decade. (See Table 4.) Private contributions to university research (industry and nonprofits) fell as low as 8.7 percent (1967–69). At this juncture universities finally were forced to face the consequences of overdependence on a single source—the condition that had worried university leaders during the preceding postwar era.

TABLE 4

FEDERAL DEPENDENCE

Share of Separately-Budgeted University R&D Supported by Federal Funds

1953	1960	1966	1976	1987
53%	63%	74%	67%	63%

SOURCE: National Science Foundation

The Stagnant Decade, 1968–77

The momentum imparted to academic science by the launch of Sputnik lasted for ten years. The year 1968 represents a kind of apogee for the university research system in terms of real expenditures and federal support for research. This was not solely a university phenomenon; research expenditures for the country as a whole peaked in 1968 as well. The university research economy remained roughly stable in real terms for the next seven years, through 1975, while the national research economy actually declined by nearly 10 per cent. Significant growth in university research did not occur again until 1978. The system thus experienced a decade of stagnation, which in some cases brought outright retrenchment.

Despite the transition from expansion to stagnation, the university research system changed only slowly during this decade. The federal contribution to university research fell somewhat to 67 percent. Applied research fared somewhat better than basic, so that the proportion of the latter declined from 77 percent (1968) to 69 percent (1977). Still, despite evident dissatisfaction with purely disinterested academic research, there was little movement toward a more programmatic orientation. The proportions of academic science obligations awarded by NIH and NSF remained about the same, although both agencies altered their policies by devoting significantly more of their funds to actual research. This behavior maintained the pool of project funds, but had an additional, adverse impact on universities. During the "Stagnant Decade" federal support of the kind that bolstered university research capacities was severely curtailed. Funds for R&D plant peaked at $126 million in 1965, but averaged just $35 million annually during the 1970s (current $). Federal fellowship support reached a high figure of $447 million in 1967, but stood at only $185 million a decade later. Universities were asked to do more on their own to sustain their research roles, and they were hard-pressed to meet this challenge.

These years were difficult ones for university finances. The private universities, in general, had tended to overcommit themselves during the late 1960s, and as a result concentrated on putting their budgets back into the black during the early 1970s. State research universities came under increasing pressure during the early 1970s to justify their high costs to egalitarian-minded legislators. From about 1968 it was virtually taken for granted that a major new federal program would have to be initiated in order to rectify the financial conditions prevailing in higher education. When it came in 1972, however, Congress provided expanded forms of student financial aid instead of institutional aid that would have been of immediate succor to the research universities. Under these conditions, few institutions were able to augment their research capacities during the 1968–1977 period. Their problems were not just with income, which in most cases continued to rise, but also with the rapid growth in non-instructional demands, such as energy costs, administrative requirements, and the necessity of meeting federal regulations. Research was in fact severely crowded as an institutional priority by other concerns.

Decentralization nevertheless continued as the proportion of federal research funds received by the top ten universities declined from 29.1 percent in 1967 to 25.8 percent in 1975. It seemed, however, that the stagnation in research funding and the persistent financial difficulties facing universities would now favor the leading institutions.[19] As the competition for research funds became more intense, the advantage of those universities with the highest peer-rated faculties ought to have become more pronounced. Sustaining a research commitment also seemed to demand a larger investment of institutional funds. At the second-tier research universities, however, a de-emphasis of research seemed apparent. Insofar as institutions were adapting to this situation, they appeared to be contemplating a withdrawal from research commitments—either to turn toward undergraduate and professional teaching, or to abandon broad research/graduate programs for more specialized undertakings. It consequently appeared that the country could not sustain as research universities the number of institutions that had aspired to that status in the 1960s and that the secular trend toward decentralization of university research was about to be reversed.

The Current Era: 1978–1988

In actuality, the university research system neither continued to stagnate nor contracted toward the peak institutions. Instead, the system renewed its secular expansion beginning about 1978. In ten years (1977–1987) it grew 56.5 percent in real terms—not a bad showing for a mature system that experienced little growth in students or faculty. Moreover, in a largely unforeseen development, support for the increase in research came disproportionately from nonfederal sources. Federal funds for university R&D increased by 10 percentage points less than the average, while nonfederal sources grew by twenty points more. The fastest growing single source of university research support was private industry, which funded 6 percent of the 1987 total. That six-percent figure, in fact, understates the rising importance of university-industry ties. A good part of nonprofit support of academic research (perhaps another 3 percent of the total) probably comes from corporate or industry-related foundations;

and some state support is now directed toward subsidizing university-industry linkages. The expansion of research support from nongovernmental sources has increased the actual and perceived pluralism of the system. No longer are the research universities considered to be wards of the federal government: When Robert Rosenzweig and Barbara Turlington wrote of this in 1982 they deliberately referred to "The Research Universities and Their Patrons."[20]

The decade of the 1980s was reasonably prosperous for the research universities generally; their instructional budgets grew by roughly 30 percent in real terms (1974–76 to 1984–86). This figure most likely understates the improvement that has taken place in their financial positions. The privatization of university income has almost certainly been more pronounced than that for just research funds. The great gains of the 1980s for universities have come from increased tuition (the delayed payoff from the expansion of student aid) and voluntary support. Without a doubt, many universities have used these funds to enhance research capacity; but it has also been common to bolster those aspects of the university that most directly affect its ability to attract students and raise money—admissions, development, student aid, and perhaps those structures that most appeal to students and alumni. Unlike the 1960s, universities have acted conservatively toward creating new faculty lines.

The financial conditions of the 1980s have been especially beneficial to the leading research universities. They have well established channels for raising voluntary support and a surplus of applicants with little sensitivity to price. Despite these factors, and despite the continued stiff competition for federal research funds, the leading research universities have by-and-large not kept pace with the growth of total R&D expenditures. The proportion of federal R&D funds received by the ten largest recipients declined to 22 percent in 1987; their share of total R&D expenditures was even less—19 percent.

Smaller research universities, or at least some of them, have been increasing their share of research funding. (See Tables 5 and 6.) It is difficult to characterize these advancing institutions with any precision. They include many state institutions from Sunbelt states where, at least until recently, economic growth has provided the underpinning for increases in enrollment and state support. Also prominent are public and private universities with close ties to industry, especially engineering schools. For the former group, the old formula of more students and higher appropriations seems to have translated into greater research capacity. For the latter group, links with the fastest growing segment of the research economy have produced above average growth. More generally, this pattern would indicate that the growth in the research economy during the 1980s has been due substantially to the initiative and adaptation of individual institutions.

Conclusion.

The university research system of the United States has retained its fundamental features despite a century of growth and the superimposition of significant additional components. Most importantly, the research capacity continues to depend in large measure on the vigor of individual universities, while the amount of research performed depends upon funding from the extramural research economy. Secondly, these external funds represent a shifting balance between support for disinterested basic research in the academic disciplines and programmatic research in keeping with the interests of funders. The dynamics of the university research system, past and present, can be portrayed in terms of these two dichotomies.

TABLE 5

RELATIVE SHIFT IN R&D EXPENDITURE SHARE: 1974–76 TO 1984–86

Slightly Increased Research Share	Slightly Decreased Research Share	Decreased Research Share
Cornell	MIT	Michigan
Stanford	Yale	UC Berkeley
Texas	Illinois	Princeton
Caltech	UCLA	Wisconsin
	Minnesota	Harvard
		Penn
		Columbia
		Chicago

SOURCE: National Science Foundation

TABLE 6

CHANGE IN R&D SHARE OF LARGE RESEARCH UNIVERSITIES 1974–76 TO 1984–86

	Positive Change			Negative Change		
	>20%	10 to 20%	0 to 10%	0 to-10%	-10 to-20%	<-20%
Universities Performing> 2.0% in 1974–1976	0	2	1	2	5	2
Universities Performing 1.0–2.0% in 1974–1976	4	1	3	8	0	4

SOURCE: National Science Foundation

The dependence for research capacity upon the resources of individual universities has in one sense been a traditional weakness of the American system. Only in the decade after Sputnik did the federal government assume the responsibility to enhance research capacities across a wide range of universities. Today, when the litany of problems confronting research universities is recited, most of the items can be associated with this issue: the lack of support for infrastructure, including instrumentation; and the impossible demands upon research university libraries. The inadequate support for graduate students, and the consequent concern about the pipeline for future scientists, would also belong partly with this list.[21] In addition, the heterodox efforts of a few universities to lobby Congress for special appropriations would seem to be a pathological expression of these university needs—and university aspirations.

In another sense, the continued decentralization of university research conveys a different message. A growing number of research universities are clearly managing to expand their research capacities. The decentralization of university research is not a result of federal pressures to spread research funding more widely: total expenditures for research are more decentralized than expenditures from just federal funds. Research has increased as a university priority since the stagnant years of the 1970s. The result, despite relatively little assistance from the federal government, has been to augment the research capacity of American universities. The research economy has grown moderately during the 1980s, but the current fear is that federal budgetary restrictions will preclude a continuation of this expansion, which is necessary to maintain the overall health of the university research system. The positive side of this situation is that the system has been growing less dependent upon federal funds. Decentralization has tended to increase the pluralism of funding sources. Most likely, advancing research universities have been able to tap local sources of support for their research. By and large, however, this has meant a greater proportion of programmatic funding.

There can be little doubt that the 1980s has witnessed a disproportionate growth in programmatic support for academic research. Not only has funding from industry been the fastest growing component, but it has been supplemented by numerous federal and state programs designed to promote technology transfer and closer links between universities and industry. In one respect this trend represents an overdue correction to the attitude of disdain for applications and business that reigned during the post-Sputnik decade. But it has not been an unmixed blessing. Critics have worried, much as they did in the postwar era, about the diversion of scientists from basic research and about the possible perversion of essential elements of scientific communications. In addition, programmatic support cannot substitute in most fields for disinterested disciplinary research. Above all, it is necessary to maintain the vigor of the basic research goose if the golden eggs of technology are going to be gathered.

On the whole, though, the current balance may be a healthy one. The research universities today may be more responsive to the needs of American society than any time in the past. If so, this happy state is not the result of any particular policy. Rather, it stems from the habits of flexibility and adaptability that have well served American universities throughout the first century of their history.

NOTES

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8. *Geiger, To Advance Knowledge,* pp. 67–93.

9. The material in this section draws chiefly upon Geiger, *To Advance Knowledge.*

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Japan

THE UNIVERSITY, INDUSTRY AND RESEARCH IN JAPAN

James R. Bartholomew
The Ohio State University

Over the past several decades, Japan has created a substantially different type of research system from that which exists in the United States today. The Japanese system links basic research more closely with industry. It relies far more heavily on private financing, but with government interventions in critical fields. And it displays a prominent inclination to change fundamental elements of the academic system in ways that will hopefully be beneficial to research. It is a matter of opinion whether one national system is superior to the other: such judgments must depend partly on the objectives defined. The point is simply that Japanese procedures and experience can be instructive for Americans who seek alternatives to elements of current practice here and are thus worth considering in a framework of comparison.

Current rethinking of research organization in the United States and the place of teaching in it could certainly benefit from the experience of Japan. In all Japanese universities from the most prestigious to those of lowest stature, professors have traditionally been expected to teach as well as do research. Prior to 1918 there were no exceptions to this pattern at all; and in the period since 1945 even university presidents have only been exempted from teaching on a temporary basis. Much has been written about the institutional innovativeness of Tsukuba University and its attached Science City (created in 1973).[1] But here as elsewhere teaching is deemed essential to the professorial role.[2]

Nevertheless, in special circumstances the Japanese *have* created academic (i.e. university affiliated) roles exclusively for research without any teaching. This happened for the first time in 1918 when, as a result of difficult adjustments linked to World War One, the research professorship was established at Tokyo University. The conditions surrounding this event are instructive. Prior to 1914 Japan had relied very heavily on foreign (especially German) sources of supply for scientific knowledge and technical products—pharmaceuticals, industrial chemicals, scientific instruments. However, the Anglo-French naval blockade of Imperial Germany made such imports impossible; and the country was entirely thrown back on its own resources. The years 1914–1919 thus witnessed significant intellectual and institutional initiatives in science, including a small number of research professorships established for engineering and physics in connection with the University's Aeronautics Institute (founded 1918).[3] More recently there have been other initiatives which ultimately seem linked to a similar motivation. Beginning in the early 1970s, the Ministry of Education began to establish what are rather inelegantly known in English as National Research Institutes for Joint Use by Universities. These facilities, which now number six, carry on research in high energy physics (at the well known KEK laboratory at Tsukuba), polar studies, molecular science, physiology and biology. As their collective name implies, they are open to researchers from any academic institution. Staff members hold academic titles (professor and the rest) but are not required to do any teaching. There are variations on this pattern as illustrated by the Research Institute for Fundamental Physics of Kyoto University where professors may free themselves of teaching under shorter term arrangements of up to five years.[4] In all of these cases such arrangements seem to reflect a sense among decision-makers either that independent research capability is essential or that Japan itself holds a leadership position in the particular specialty. But one cannot extrapolate from the experience of these specialties to the research system as a whole. A combination of research and teaching is still very much the norm.

Relations between universities and private industry in Japan have shown nothing like the consistency of thinking about the academic role of the teacher-researcher. Prior to 1914 Japanese companies had little interest in developing research capabilities either alone or in conjunction with universities. But they did employ university professors as ad hoc consultants regarding foreign technology so often as to generate allegations that professors were neglecting students and their own research. These criticisms intensified when the war broke out, but the wartime need for indigenous research brought, if anything, a more (not less) intimate relationship between firms and the academy as cooperation not only continued but assumed a higher level. Establishment of the prestigious Research Institute for Physics and Chemistry in 1917 was accomplished by a formal partnership between academics and firms and in many ways set the tone for such relations in the interwar period.[5] Kotaro Honda's Institute for Metals Research at Tohoku University, for example, relied heavily for its financial support on the Sumitomo group of business enterprises.[6]

A pattern of considerable (though never total) estrangement between firms and universities developed after 1945. Many academic scientists became hostile to business on the (mostly incorrect) Marxist assumption that Japanese capitalism had encouraged Japanese militarism, while many firms were so interested in acquiring Western technology as to give short shrift to domestic research. One can see the negative consequences of this partial estrangement both for research and the general welfare in Japan's efforts to develop a nuclear power industry during the period 1953–1980. Following President Eisenhower's “Atoms for Peace” address to the U. N. General Assembly in December 1953, business and political circles in Japan became captivated by the notion that atomic power offered *the* solution to Japan's energy needs and decided to import nuclear reactors from Britain. Prominent members of the scientific community—especially Nobel physics laureate Hideki Yukawa—cautioned against this excess of optimism and reminded all concerned of the pitfalls involved. The scientists emphasized that atomic energy was not at that time a “proven” technology and that to import it successfully would require more research, a point which was widely accepted in Europe, even among groups which were planning the sale. But political and business leaders rejected further research, claimed that the technology was safe and dismissed the scientists' views as self interested and alarmist. The result was an inefficient nuclear industry and numerous power plant breakdowns through the end of the 1970s.[7]

The latter half of the 1970s saw the emergence of a different, more cooperative pattern between firms and universities, which has continued to the present and in many respects revives the pre-war pattern. Firms in recent years have sold or leased research equipment to universities at very low prices and have in some cases given laboratory access to professors and graduate students.[8] Most importantly, academic scientists are increasingly being named to head large scale research programs partly funded by government but extensively carried out in industrial laboratories. Dr. Tohru Moto'oka, professor of electrical engineering at Tokyo University, has served as director of the 5th Generation Computer Project since 1981; while a colleague, Dr. Shoji Tanaka, professor of applied physics at the same institution, is heading up a major project in superconductivity.

Even while acknowledging academic scientists' renewed prominence in major research projects, it must be stressed that industry has been the major player in Japanese research for all of the postwar period. About two-thirds of all Japanese research and development expenditures have been contributed by private firms.[9] While this pattern varies sharply from that of other leading industrial democracies where government funding is prominent, it is readily explicable in the Japanese context. Between 1880 and 1920 nearly all research funding was provided by the government. However, the 1920s saw a significant shift of funding away from the purely academic setting toward a mixture of corporate laboratories (a new phenomenon in Japan at that time) and mission laboratories attached to government ministries. This was a worldwide trend, but it also derived in Japan from a widespread belief that university research was seriously constrained by factional infighting, professional favoritism and an unfavorable climate generally.[10] In the 1930s and early 1940s academic researchers were heavily co-opted by the military for war-related work through the Japan Society for the Advancement of Science, a pattern which later encouraged estrangement between society and the academy and led industry to go its own way in research. Then during the Occupation years of the late 1940s, American policy actively encouraged Japanese decision-makers to emphasize applied research at which industry excelled at the expense of basic research (where universities were active) as a basic strategy for rebuilding the country. The American physicist H. C. Kelly, who was particularly influential in developing this posture, actually called basic research in 1948 a “luxury in the light of existing conditions.”[11]

Industry's influence has also been great in the realm of education. Following a 1954 initiative from the Ministry of Education, the Nikkeiren (Japanese Federation of Economic Organizations) issued a formal report in 1956 which criticized the law-liberal arts biases in the selection of university students and demanded more emphasis on science and engineering. In 1961, the cabinet of Prime Minister Hayato Ikeda acted on this recommendation by increasing dramatically the number of university places reserved for students in science and engineering. Whereas matriculation slots for such students were 28 percent of the total in 1952, by 1968 they constituted 46 percent. A comparison between Kyoto University and Stanford University (which are comparable universities and sister institutions) illustrates the result of this policy at present. Some 34 percent of Kyoto University undergraduates are currently majoring in engineering; at Stanford the figure is 7 percent.[12] Once we take into account the particular career patterns of Ikeda and most of the postwar Japanese prime ministers, who have generally been involved in business *and* government, it will be readily apparent that industry has played a very large role in formulating both research policies and those for education.

Historically, however, it was the Japanese government that played the greater role. Prior to World War One industry was rarely willing to spend money on research on the assumption either that it would cost too much or that imported knowledge was sufficient for its needs. Over 90 percent of research was concentrated in university and government laboratories and the national government paid most of the bill. The first indication that private industry might support research came in 1900 with establishment of the Industrial Experiment Laboratory in Tokyo. This government facility was established to perform contract research on a fee-for-service basis for the emerging chemical industry. The Laboratory did well enough that its technical staff even doubled to about two dozen investigators and assistants after the Russo-Japanese War in 1905. However, the significance of this venture at the time should not be overstated. A member of parliament who made a formal inquiry in 1913 noted that the Laboratory was poorly located, largely unknown to potential customers and had to face competition from a nearby Commercial Exhibitions Hall (supported by the government) where *foreign* machinery and technical apparatus was displayed for the edification and enrichment of private manufacturers![13]

Until 1918 Japan had a centrally controlled, more or less unitary system for scientific and technical research and education. The Ministry of Education supervised a national network of so-called imperial universities and professional schools of lesser stature where undergraduate instruction in basic science and certain applied fields was available. At the graduate level, instruction and training were only available at the four imperial universities (Tokyo, Kyoto, Tohoku and Kyushu). Significantly, work in engineering was only available at the imperial universities. In medicine, however, degree programs and research facilities were available at a number of prefectural government medical colleges and two proprietary medical academies.

The monopoly of scientific and technical education and research by a small number of government institutions was for many years a matter of policy, though rarely articulated in so blatant a form. Between 1877 and 1914 there were several attempts to establish degree programs in technical disciplines at private institutions (Keio, Doshisha and Waseda). But in every case the Ministry of Education refused to grant equivalency status to the diplomas awarded their graduates and by doing this brought about the desired result, which was the formal demise of these programs.[14] Ultimately, however, the policy could not last. Technical education was expensive and public funds were simply insufficient to sustain the monopoly, particularly at a time when private industry was demanding more engineers and even scientists than the government institutions could provide. With the coming of World War One in 1914 the monopoly began to dissolve, though it was only in 1918 that the Ministry of Education was finally willing to allow private institutions like Keio, Doshisha and Waseda to use the term “university” in their names and confer degrees which were legally equivalent to those awarded by the imperial universities.[15] It should also be noted that once the system of monopoly control fell apart, there was never again an attempt to reimpose it.

Any attempt to label the government's control system for science and engineering in this early period a “unitary system” should be qualified in another way, too. While the Ministry of Education had an effective monopoly over scientific and technical education, it never had such control over scientific and technical research. The Ministry of Home Affairs was very active in medical research, particularly the domain of infectious diseases and microbiology where Shibasaburo Kitasato (who died in 1931) directed one of the world's three leading research facilities in his field at that time.[16] Similarly, the Ministry of Communications sponsored important work in electrical engineering and applied physics. And the Ministry of Agriculture and Commerce supervised and paid for a range of research activities in several fields of engineering, agriculture and (after 1917) even basic science. In fact, it was the Agriculture and Commerce Ministry which exercised control over the prestigious Research Institute for Physics and Chemistry between 1917 and 1945 where two physicists who later received Nobel prizes were affiliated for some time.

This plurality of government sponsors and funding agencies (which has continued to the present) has had significant benefits for the scientific community and the research establishment. In the earlier part of this century, it allowed scientists to play one government agency off against another and even to bargain for the "best" affiliation. Kitasato successfully opposed for twenty years (1893–1914) persistent efforts by the Ministry of Education to gain control of his laboratory.[17] In 1918 two professors of physics at Tokyo University, formally under the control of the Education Ministry, maneuvered control of the budget for the University's Aeronautics Institute away from the Ministry to constrain unwelcome interference in its affairs from that source. And members of the Faculty of Science and of the Faculty of Engineering at Tokyo University built important bridges to private industry between 1917 and 1922 *and* supported an affiliation with the Ministry of Agriculture and Commerce which allowed them freedom to maneuver between it and the Ministry of Education.[18]

There are, however, some indications that Japanese scientists since 1945 have *not* been able to manipulate the bureaucracy with this same degree of success. If this is so, it would likely be owing to three factors: a) the political estrangement between the scientific community and the government which developed after the war, b) the diffusion of formerly scarce scientific and technical knowledge to a greater number of experts and their wider deployment throughout the research system, and c) the widespread concern among officials and private industry for catching up with foreign achievements and corresponding tendency until recently to overlook or ignore domestic capabilities. On the benefit side, one should note that private universities today usually offer degree programs in technical fields and manage to support far more substantial research efforts (either in absolute terms *or* relative to the efforts of public institutions) than was true in the years before World War Two.[19]

Organizational forms in research and education have been a persisting topic of debate among Japanese observers and increasingly among foreigners with particular attention being given to the so-called university "chair system." Unfortunately the subject is rarely discussed with real clarity by either group, the objective instead being to score political or ideological "points" against perceived opponents. Briefly stated, its critics have held that an organization headed by a single full professor with professional responsibility for, and supervisory authority over a laboratory group including junior faculty and graduate students cannot be trusted to act responsibly. Allegations have varied according to time and place, but usually charge senior professors with suppressing critical, creative impulses by younger people, perpetuating favoritism and obstructing many forms of collaboration among different laboratory groups. This is not the place to discuss whether these charges are true or not, though I have addressed this issue elsewhere.[20] What I would like to do instead is comment on the origins of the chair system and other important organizational features of the academic system in which the research enterprise is today, and has been, imbedded.

When the modern academic system was first organized in the late 19th century, responsible decision-makers paid closest attention, as one might expect, to the nations perceived to be leading in the academic enterprise. At the time this primarily (but not exclusively) meant Germany; and the chair system as an organizational form is essentially that of the nineteenth century German university. However, neither at that time nor any other did Japan adopt foreign organizational forms uncritically. The German pattern called for representing every field of knowledge by a single chair headed by a single full professor. Japanese leaders rejected this so-called "one chair rule" from the very beginning in favor of the French chair system which allowed the creation of multiple chairs per discipline at a given university based loosely on enrollment or perceived societal, including academic need. Nor were the Japanese very impressed by another prominent feature of the German academic system, namely the *privatdozenten* or unsalaried private lecturers who for a time offered some competition to the salaried academics. Despite many appeals to adopt the practice, the Ministry of Education persistently (and wisely) rejected private lecturers.

The Ministry of Education showed equally good judgment in some other critical decisions about how to organize teaching and research. Basically it insisted that agriculture and especially engineering should be integral parts of the university system from the start. From its inception in 1877 Tokyo University had an engineering program; and in 1886 a full fledged Faculty of Engineering was created by combining it with an institution known as the Imperial College of Engineering (established in 1870). Agriculture for its part was taught at the Komaba Agricultural College (also founded in 1870) in Tokyo but came to constitute a Faculty of Agriculture in 1890. These initiatives were quite daring by the standards of nineteenth century European universities since only a few German institutions included agriculture and none whatsoever included engineering. The models or precedents for them were eclectic indeed. The American land grant universities authorized by the 1863 Morrill Act were one important inspiration for the decision to include applied science in Japan's imperial university system, while Switzerland's Zurich Polytechnic Institute was the primary model for Tokyo University's Faculty of Engineering. Interestingly enough, the young engineer who did the major organizational work and planning for what became the Faculty of Engineering and selected its Swiss model came from a country (Britain) which had no comparable institution.[21] It is worth making the point also that as a result of these remarkable initiatives, Japan deserves to be recognized as one of the world's pioneers in engineering education!

There can be little doubt that these and other organizational models have significantly shaped the course of Japanese research. The multiple chair system provided more prestigious positions for academic scientists than the German one-chair system would ever have allowed, while strong patterns of competition beneficial to research were set in motion and maintained by the system of chairs as a whole. In the late nineteenth and early twentieth centuries one can see this most clearly in medicine; there is every reason to believe that in recent decades one can see it in every major field of research activity. Similarly, the development of engineering research has almost certainly benefited from its association with the university despite the relative estrangement that typified relations between firms and the academy after World War Two. Kotaro Honda's program of research on metals at Tohoku University was able to benefit not only from financial support from Sumitomo Industries but equally from affiliation with a prestigious university whose administrators were unusually attentive to his requests for independence and financial support. Hitachi's successful efforts to manufacture giant turbines for generating hydroelectric power during World War One were attributed by company engineers at the time to the close cooperation they enjoyed with academic engineers at Tokyo University. And work at the University's Aeronautics Research Institute was important to the success of aircraft manufacturing in Japan during the 1930s and early 1940s. As these and other examples may indicate, the estrangement between Japanese universities and industry which typified the years between 1945 and 1974 was an historical aberration unlikely to be repeated in the future.

In fact, developments like the Fifth Generation Computer Project and the newer project on superconductivity in which industry and university are partners indicate quite clearly that the effects of World War Two have largely subsided as newer issues emerge on the scene. Current topics of discussion include the need to enhance "basic research" of the kind that will win more Nobel prizes, and how to promote international cooperation in research, that is how to attract foreign scientists to Japanese laboratories.[22] Both issues have complex facets and cannot be dealt with by any single strategy. The entire peer review system allegedly used in making research grants has come under attack and one again hears attacks on senior academic scientists to the effect that their allegedly visceral conservatism impedes the creative impulses of younger scientists working under them.[23] While some of these criticisms may on occasion be justified, it is important for American scientists, corporate managers and government officials to understand that there is very little about any of them which is actually new. Professors at imperial universities, for example, were bitterly criticized during World War One and even before for putative dereliction of professional responsibility; and in 1918 it became mandatory for them to retire at the age of sixty. The idea was that their removal from the academy would allow younger, presumably less "conservative" elements to rise to the fore and thus improve the quality of Japanese research. Significantly, this policy remains in effect today, even though hard proof of its efficacy has never to my knowledge been presented by anyone.

Similarly, the current, widely publicized discussions about peer review seem curiously ill informed and out of context. The principal claim is that under the so-called "basic support system" funds are guaranteed to researchers at a minimal level irrespective of prior accomplishment or merit. Critics, for example, decry the possibility that a professor at a major institution like Tokyo University might receive the same research stipend from these general funds as a scientist who has worked for the same amount of time at a less prestigious school. While this is not the place for extended discussion of the peer review system, it might be noted: a) that exactly this debate began in 1918 when the Ministry of Education launched its Science Research Grants Program, and b) that the criticisms about it over the years have been mutually contradictory and lacking in balance.

How to attract more foreign researchers to Japanese laboratories for extended periods of time, I believe, constitutes a more substantial challenge to the Japanese research community than any need or effort to change details of the scientific research funding system. Historically Japan has been relatively isolated from leading centers of science despite elaborate programs of overseas study, systematic journal translation efforts and other kinds of science reconnaissance. Sophisticated electronic information systems and modern air travel since World War Two have alleviated this problem in part but have hardly eliminated it. An NSF official once remarked to me that whenever NSF sponsors a scientific meeting with Japanese participants, the American organizers are urged to engage the Japanese in discussion within the first few hours of the gathering. "Otherwise," he stated, "they will sit there for three or four days without saying anything."[24] Another aspect of the same problem is the growing realization among Japanese scientists that Nobel prize winners have often been the pupils and colleagues of previous Nobel recipients.[25] There is thus a growing (and I think well founded) belief in Japan that unless their scientists can somehow become a more intimate part of this elite human network, they are destined to remain at a second class level.

While the Japanese have been poorly served by their isolation from the international research community, they have been well served by their sensitivity to, and flexibility regarding, the organizational and institutional frameworks most suitable to the research enterprise at the various stages of its worldwide evolution. European countries (as the late Joseph Ben-David argued in a noted study for the OECD) have been remarkably hidebound in their organizational conservatism.[26]

Superficial impressions to the contrary notwithstanding, the Japanese have displayed a remarkable openness to new organizational forms. They avoided the trap of the "one chair rule" and the *privatdozent* system in the 19th century. They established research professorships when these seemed desirable. They were able to change the retirement age for professors in 1918 when that seemed essential. And they developed elaborate patterns of university and industry cooperation in the 1930s and 1940s and again since about 1975. To the extent that their current problems or future challenges can, or need to be, solved through institutional changes, one can be confident of their long-term success.

NOTES

1. J. L. Bloom and S. Asano, "Tsukuba Science City: Japan Tries Planned Innovation," *Science,* Vol. 212 (12 June 1981), pp. 1239-1247.

2. A. M. Anderson, *Science and Technology in Japan,* London: Longman, 1984, pp. 88–89.

3. J. R. Bartholomew, *The Formation of Science in Japan: Building a Research Tradition,* New Haven and London: Yale University Press, 1989, pp. 199–237.

4. Anderson, *op. cit.,* pp. 88–101.

5. On the founding of the Research Institute, see Bartholomew, *op. cit.,* pp. 212–217. Interwar relations are discussed by M. A. Cusumano, " 'Scientific Industry': Strategy, Technology, and Management in the Riken Industrial Group, 1917 to 1945," *Managing Industrial Enterprise: Cases from Japan's Prewar Experience,* edited by W. Wray, Cambridge: Harvard Council on East Asian Studies/Harvard University Press, 1989, pp. 269–315.

6. N. Kawamiya, "Kotaro Honda: Founder of the Science of Metals in Japan," *Japanese Studies in the History of Science,* No. 15 (1976), p. 151.

7. Details can be found in Hideo Sato's seminal paper "The Politics of Technology Importation in Japan: The Case of Atomic Power Reactors," pp. 7, 16, 22, 25, 48–49. The paper was prepared for the Conference on Technological Innovation and Diffusion in Japan sponsored by the Social Sciences Research Council and held in Kona, Hawaii, February 7–11, 1978. The arguments are also summarized in Bartholomew, *op. cit.,* pp. 278–279.

8. Anderson, *op. cit.,* p. 107.

9. *Ibid.,* p. 104.

10. Bartholomew, *op. cit.,* pp. 276–277.

11. Quoted in S. Nakayama, "The American Occupation and the Science Council of Japan," *Transformation and Tradition in the Sciences,* edited by E. Mendelsohn, Cambridge: Cambridge University Press, 1984, pp. 357–358.

12. For additional details on Kyoto University, see Anderson, *op. cit.,* p. 83.

13. Bartholomew, *op. cit.,* pp. 119–120.

14. *Ibid.,* p. 103.

15. *Ibid.,* p. 201.

16. J. B. Blake, "Scientific Institutions Since The Renaissance: Their Role In Medical Research," *Proceedings Of The American Philosophical Society,* Vol. 101, No. 1 (February 15, 1957), pp. 31–62.

17. For details, see J. Bartholomew, "Japanese Culture and the Problem of Modern Science," *Science and Values,* edited by E. Mendelsohn and A. Thackray, New York: Humanities Press, 1974, pp. 109–155.

18. Bartholomew, *op. cit.,* p. 223.

19. For details, see Anderson, *op. cit.,* pp. 82–89.

20. See Note 17 above for details.

21. Bartholomew, *op. cit.,* pp. 89–124.

22. In 1988, Dr. Enrique Marcatili of Bell Laboratories, a leading specialist in optical communications, accepted a chair at Tokyo University endowed by Nippon Electric Corporation (NEC), the first event of its kind in Japan. Japanese officials and scientists hope this appointment will constitute a trend. For details, see the remarks of Dr. Hiroshi Inose in "Discussion: Scientific Exchange, Getting the Word Out," *Look Japan,* (March 1988), p. 32.

23. See, for example, the views on the peer review system of Dr. Susumu Tonegawa, Nobel laureate in medicine for 1987, as reported by Stephen Kreider Yoder, "Native Son's Nobel Award Is Japan's Loss," *The Wall Street Journal,* Vol. CCX, No. 75 (Wednesday, October 14, 1987), p. 26.

24. Private conversation, January 26, 1983, at Dedham, Massachusetts.

25. Dr. Yoneichiro Sakaki, Professor of Electrical Engineering Emeritus at Nagoya University, makes this point in "Kenkyusha no aida no ningen kankei no taisetsusa," *Gakujutsu Geppo,* Vol. 40, No. 12 (December 15, 1987), p. 918.

26. J. Ben-David, *Fundamental Research and the Universities,* Paris: Organization for Economic Cooperation and Development, 1968.

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Soviet Union

THE RUSSIAN RESEARCH SYSTEM

Mark B. Adams
University of Pennsylvania

Today a cold and cleansing wind is blowing in the Soviet Union. Under *glasnost'* and *perestroika,* layers of long-standing ideology and myth are being peeled away, and Soviets are beginning to take a hard new look at how their system really works. In the process, Soviet planners are beginning to re-examine their most time-honored assumptions. It is time for us to re-examine some of our own.

The Soviet research system has played a uniquely important role in Western science and technology policy. As influential as British, French, and German models of science have been in the past, in the post-World War Two period, our perceptions of Soviet science have most often shaped our policies. This may help to explain why it has been so difficult to get an objective fix on Soviet developments: what we have perceived has depended on wishful thinking, Western policy agendas, and the politics of the beholder.

Ever since the Bolshevik Revolution of 1917, Western policy-makers have found the Soviet example uniquely instructive. Yet all too often they have drawn the wrong lessons. In the 1930s, influential left-wing British scientists saw Stalinist centralized planning as worthy of emulation, and Western physicians often took the Soviet health care delivery system as a model.[1] With the rise of Lysenkoism after World War Two, the Soviet example became a cautionary one, stimulating a Western "freedom of science" movement which took it as proof that science could not prosper in the absence of political democracy and intellectual autonomy. The wholesale destruction of Soviet genetics in late 1948 reinforced this conviction, leading many in the West to lament the death of science in Russia and to dismiss that nation as a scientific power.[2] When the Soviet Union exploded its first atomic bomb, this mindset led many to assume that its "secret" must have been stolen from the West.

It is no wonder that the launching of Sputnik in the fall of 1957 produced a shock wave in Washington from which that city has not yet fully recovered.[3] In the United States, there followed fears of "the missile gap," the instigation of advanced placement courses in high schools, new science curricula, the "space race" to the moon, and, of course, the emergence of the history of science as an academic discipline. In military and space technology, the Soviet research system once again had to be taken seriously.[4] Only in recent months, with the apparent collapse of traditional Soviet communism as a viable economic and ideological system, has the USSR yielded pride of place in Western preoccupations to Japan.

For an historian of Soviet science, what is most striking about these various and sometimes opposite perspectives is the common orientation they have shared. For example, the Bolshevik Revolution of November 1917 is almost always treated as an historical watershed. The assumption that the Revolution marked some sort of essential discontinuity has been institutionalized in Western academe, where the pre-revolutionary and post-revolutionary periods are commonly taught by different historians, and "Sovietologists" form a separate interdisciplinary field with their own issues, approaches, and problematics.

Another common view is that Soviet science is somehow essentially different from our own because it is socialist, or Marxist, or ideological, or totalitarian—or simply because, as L. C. Dunn once noted, Russians tend to put a "peculiarly Russian" slant on things.[5] Even those historians who have sought to "normalize" our view of Soviet science have found themselves preoccupied with its differences, and this has produced peculiar asymmetries in the Western literature. Nearly all analysts agree that Soviet achievements in mathematics have been most impressive, yet there has been almost nothing written on its history. Instead, Western literature on Soviet science has been overwhelmingly preoccupied with two themes that highlight fundamental differences: Lysenkoism and dialectical materialism. Of course, Lysenkoism remains a hot topic in the *glasnost'* literature; the same cannot be said for the discussions of Marxism and science, however, suggesting that the Western preoccupation with that topic has more to do with longstanding Western philosophical agendas than current Soviet concerns.[6]

Finally, Soviet science is often described and interpreted in moral terms. Even the best studies by émigrés and Soviets alike (and even some Western historians) sometimes read like morality plays in which there are few shades of gray.[7] The same historical figures can play quite different roles in different productions, of course. During the Lysenko period, the Soviet press described Gregor Mendel as an "idealist Austrian monk"; following the repudiation of Lysenkoism, he became a "materialist Czech scientist." Over the years, Soviet geneticist Nikolai Vavilov has been variously described by the words "saboteur," "traitor," "sell-out," "hero," "martyr," and "saint." Even today, old interpretive habits die hard: current Soviet publications remain profoundly polemical and polarized, often contesting, in abrasively self-righteous tones, over whether N. W. Timoféeff-Ressovsky, N. P. Dubinin, and other living and dead scientific figures were heroes or villains.[8]

These orientations have had analytic consequences. From the perspective of many Westerners who study science or formulate policy, the Soviet example may be variously seen as inspiring, tragic, or cautionary, but it can only be marginally relevant. We did not, after all, experience a Bolshevik Revolution; we are not "peculiarly Russian"; and our scientists are not (as a rule) saints, heroes, villains, or martyrs.

In recent years, however, we have come to understand our own science in a new way. If an earlier historical tradition focused on great men and great ideas, newer work has come to understand science in the context of the disciplines, institutions, and networks that have structured modern science as an international human enterprise. This new perspective makes possible a somewhat different picture of Russian and Soviet science, one that makes it seem more familiar and promises to give us a better fix on its future prospects.

Origins of Modern Russian Science

Before the mid-19th century, Russian science was largely a European import whose institutions, personnel, and traditions were borrowed from abroad and imposed from above. Peter the Great created the Academy of Sciences in his new Baltic capital of St. Petersburg in 1725, yet for more than a century thereafter its operating languages were Latin, French, and German, and its activities were dominated by visiting or resident scholars from the West. Following the Napoleonic wars, which brought Tsar Alexander I and his Russian troops into the heart of Europe, there was renewed interest in European science and technology. But from the accession of Nikolai I in 1825 until his death in 1855, Russia retreated into cultural isolation.

In the late 18th and the early 19th centuries, Tsarist cultural politics vacillated between fascination with European ideas (often accompanied by perceptions of Russian “backwardness”) and autocratic nationalistic isolation (accompanied by perceptions of Russia's unique character and status). Native research agendas focused primarily on the exploration of the vast Russian frontier. The military conquests that created the Russian Empire were increasingly accompanied and followed by state-sponsored surveys of the cartography, geography, geology, natural history, and ethnography of its new territories. Throughout this time, Russia was ruled by the Tsar, his advisors, and his state bureaucracy; its nobility and gentry had been originally granted their holdings through state service; and vast numbers of Russian peasants were tied to the land as serfs.

Then almost exactly 125 years ago, Russia underwent a profound crisis, with remarkable parallels to recent events. The regime of Nikolai I had been founded on nationalism, autocracy, religious orthodoxy, and a widespread belief in both the morally corrupt character of Western economics and the invincibility of the Russian army: that army's defeat in the Crimean War triggered vast changes and raised fundamental questions about Russia's competitiveness in a modern world. Following the accession of Alexander II, the early 1860s saw “Great Reforms” that were sweeping and fundamental in character, encompassing the abolition of serfdom, the creation of a largely independent judicial system, and a series of military, rural, and administrative reforms aimed at modernization. Like the governments of other proud and isolated countries bested by Western military technology (Japan comes to mind), Tsarist administrators faced a problem: how to bring in Western science and technology without also bringing in those alien, corruptive, Western values, politics, and ideologies that threatened Russian tradition and identity.

These events unleashed forces that would dominate Russian life for the remainder of Tsarist rule, and beyond. Culturally, the period 1865–1910 produced the great literature and music for which Russia is justly famous—Dostoevsky, Tolstoi, Chekhov, Moussorgsky, Tchaikovsky, and Stravinsky. Economically, Tsarist governments launched a series of attempts to solve the “rural problem,” to industrialize Russia, to develop steel and railroads, and to encourage foreign investment and native entrepreneurship. With these efforts came a growing importance of merchants and industrialists in the civic life of Russia. Politically, Tsarist regimes sought to control the pace of change and to ensure stability; at the same time, there was increasing political instability, and the period saw a series of radical parties and revolutionary movements, hundreds of assassinations of Tsarist officials (including the “Great Reformer” himself, Alexander II), and a growing disaffection by intelligentsia, many of whom looked to Western political and parliamentary models.

Modern Russian science thus owes its origin to the decades following the Russian loss of the Crimean War, a fact long acknowledged in both Soviet and Western literature. But quantitative studies of Russian scientific and technical publications allow us to get a more precise fix on these developments, and raise interesting problems with traditional interpretations. Building on work by the pre-revolutionary Russian bibliographer N. M. Lisovskii, my own quantitative studies have indicated that the number of Russian scientific and technical periodicals began to grow exponentially around 1880; that this growth outpaced all other forms of publication (theological, literary, artistic); and that this growth rate remained remarkably constant over time, doubling the number of periodicals every eleven years from 1880 through the late 1930s.[9]

How and why did this "take-off" in Russian science and technology occur? The phenomenon needs to be studied in more detail, but preliminary work reveals some suggestive patterns. First, the quantitative output of certain economic indicators manifests an almost identical plot: as measured by the number of kilometers of railroad lines, steel output in tons, or (admittedly rough) estimates of Russian GNP, the Russian economy experienced an "exponential take-off" at the same time as Russian scientific and technological publication. This suggests that the rise of Russian science and technology may be linked to the development of industrial capitalism in Russia. Second, the most rapid growth in periodical publications occurs in provincial centers such as Kiev, Kharkov, Odessa, and Kazan. This suggests that the many historical accounts of Russian science that focus almost exclusively on developments in St. Petersburg and Moscow may be missing much of the "action."

Finally, the dating is intriguing. It has been commonly assumed that this newly emergent Russian science was associated with the Russian left, or at least with "progressive" or "liberal" times. It is true, of course, that in the 1860s some sciences (Darwinism, physiology, psychology) were embraced by political radicals; but note that the closest approximation of the initial point of exponential growth is not the "liberal" 1860s but rather 1880—at the height of political reaction—and it proceeds at a fairly continuous rate, doubling every eleven years, far outstripping other kinds of scholarly publication by the turn of the century. It now appears that, although conservative Tsarist censors were suspicious of the political and ideological "baggage" that often seemed to accompany contemporary English, German, and French science, they were not hostile to science or technology itself; indeed, they understood the development of Russian science and technology to be vital to their country's economic development and military strength.[10] These "conservative" times also correspond to the wide popularity in Russia of a kind of positivist philosophy that asserted the essentially objective, value-neutral, a political character of science; and this consensus philosophy became the credo of a newly self-conscious Russian scientific community, broadly diverse in politics but uniformly (and even aggressively) scientistic in outlook.

In the late 19th century, then, the dialectics of modernization cast science in a role that was at once politically innocuous and politically central, wedding "objective" natural knowledge with nationalism. Just as Russian science was beginning its "take-off," the Russian Academy became dominated by native Russian scientists for the first time in its history. Universities opened new chairs, and science professors who had previously trained only a few graduate students were now creating whole schools. Moscow University and St. Petersburg University remained the centers of higher education; but there was a great expansion in provincial science, and important departments of mathematics, chemistry, and bacteriology arose in such centers as Kazan, Odessa, Kiev, and Kharkov. Postgraduate training abroad in leading scientific centers became common practice, and Parisian and German universities, institutes, and medical schools were flooded with Russian students, many of them women. New technical, engineering, and agricultural schools were opened.

The generation of Russian scientists and scholars who began their careers at the turn of the century had grown up breathing this new atmosphere and were products of an excellent Russian university system in which science faculties were playing an increasingly central role. Most spent several post-graduate years abroad, where they absorbed the new trends in

European thought generally, including the music of Wagner, the philosophies of Bergson and Spengler, and the new work on radioactivity, economics, sociology, anthropology, experimental biology, and hormone research, as well as other enthusiasms of the day.

In Moscow they clustered around Shaniavsky University, the Beztuzhev courses, the Lebedev Institute, and other privately or municipally funded institutions. To gain support for their enterprises, they appealed to Russian industrialists and philanthropists, and resurrected the journal *Priroda* as a mouthpiece, where they published accounts of the latest Western and Russian research and reported on scientific societies, institutions, and funding patterns in Germany, France, Britain, and America. This group also shared the contemporary Western preoccupation with new hybrid or "borderland" fields, and between 1900 and 1930 there was a striking profusion of new interdisciplinary theories and fields, including V. I. Vernadsky's "biogeochemistry," P. P. Lazarev's "biological physics," N. N. Semenov's "chemical physics," and V. N. Sukachev's "plant sociology." One also sees in the period 1905 to 1917 a growth in research in new settings created by entrepreneurial scientists in such fields as experimental biology, medicine, and bacteriology.

Around the time of World War One, Russian science did not look as different from American science as one might suppose. And this did not fundamentally change following the Revolution. Although private philanthropic funding was nationalized in the 1920s, much of the research that had been supported philanthropically before the Revolution was now absorbed under the rubric of the appropriate commissariats, several of which were headed by the personal friends of the people who had developed those institutions. Furthermore, while there was significant loss of scientific and technical personnel during the wars (through emigration, injury, execution, famine, and disease), by 1925 many of those who had died or emigrated had been replaced by bright, younger, entrepreneurial scientists who used the new opportunities to pursue their pre-revolutionary agendas and to create new fields. Perhaps some of the growth in the early 1920s was due to the "pruning effects" of the troubled times. Whatever the reason, the mid-1920s witnessed an extraordinary flowering of Russian science—the creation of population genetics in Moscow, remarkable work done at Ioffe's Physicotechnical Institute in Leningrad, and a whole variety of other fields where Russian workers gained world prominence.

I see these developments in the 1920s largely as a natural outgrowth of trends started in the pre-revolutionary period. As noted earlier, there is a widespread assumption that the Bolshevik Revolution marked a great divide, with disagreements over whether it was the worst thing that ever happened to Russian science (a common view in earlier émigré literature) or the best (the traditional Soviet viewpoint). For a time, it appeared that quantitative studies supported the Soviet view. For example, in his influential booklet, *Little Science, Big Science,* Derek Price tabulated an extraordinarily rapid exponential growth in Russian scientific publication in the decade after the Revolution, which he saw as confirming its positive effects.[11] However, this finding turned out to be a technical artifact: in counting the cumulative number of scientific periodicals at a time of rapid expansion, Price saw little to be gained by subtracting for journal "deaths." I have documented elsewhere that the period 1917–1924 saw a considerable reshuffling of journal names, rubrics, and sponsors.[12] When journal "deaths" are subtracted, a very different picture of the period emerges. The number of scientific periodicals grows at a rapid exponential rate from 1880 through 1917, falling off rapidly during the three civil war years. Under NEP (*Novaia Ekonomicheskaia Politika* or New Economic Policy), periodicals start up again (often under somewhat different names and auspices), until roughly 1925, when the total has achieved the number that would have been reached by a constant continuation of the pre-revolutionary growth rate. Thereafter it resumes that same rate of growth until the late 1930s. The extraordinarily rapid growth in the number of Russian scientific periodicals 1921–1925 can thus be seen as "making up for lost time" by compensating for the dramatic fall-off during the civil war.

Despite the Revolution, Russian science in 1925 was not that different from 1915. The same institutions dominated (often renamed and with new patrons). Russian students could still do graduate work in Europe with relative freedom, there was a large degree of international contact, training and research were vigorous, and the relative isolation during the Civil War may actually have contributed to the flowering of certain especially strong Russian traditions. In sum, Russian science between 1880 and 1930 was a vigorous and rapidly growing enterprise centered in universities, scholarly societies, agricultural and engineering schools, not that different from Western science in its intellectual traditions, institutional foundations, ideological orientation, and geographical diversity.

Big Science Soviet-Style: From Stalin to Brezhnev

All of this was to end in the period 1929–1933, which marked the beginning of a qualitatively different scientific enterprise. The big change started in the year 1929, rightly remembered by Stalin's term for it, the *velikii perelom* or "year of the great break." What happened during the great break was the beginning of purge trials, the move to heavy industrialization, the collectivization of agriculture and the liquidation of the kulaks—it has been estimated that in these years between ten and twenty million people died in the countryside. There was also the heavy-handed introduction of the so-called principle of *partiinost':* bourgeois experts, so carefully cultivated in the 1920s, were now under attack and scheduled for replacement by a new group of "Red specialists" who would take their instructions from the Party. Many of the leading scientific figures who had held forth at Moscow and Leningrad University were fired from their jobs and replaced by the brightest of their young Party students. There was enormous disruption during that period.

It was at this time that the free flow of students and information between Russia and the West was largely stopped, and Russian science became isolated in a way that it had not been since the 1850s. The great American biologist and geneticist Theodosius Dobzhansky was one of those students who was in the United States on a post-doctoral fellowship with T. H. Morgan when the great break occurred; as a result of the disruptive events, he decided to stay. This is when the Stalinist system is set into place.

In the 1920s, the Party had largely left the Academy and the universities intact. They had sought instead to create their own parallel, communist institutions—for example, the Sverdlov Communist University was created, the Institute of Red Professors (to train Party people in academic and scientific fields). Parallel to the Academy of Sciences was the Communist Academy. During the great break, this strategy was largely abandoned in favor of "taking over" established institutions, creating Party cadres within them that would exert Party control. For example, the Academy of Sciences was "Bolshevized" during the "great break." Political control was increased throughout the 1930s, and by mid-decade most of the parallel "communist" institutions (such as the Communist Academy) had been dissolved. Concurrently the research system was transformed. Having harnessed the Academy, the government poured resources into its rapid expansion, leading to a doubling or tripling in the number of new institutes, in the number of graduate students, and in the size of research budgets. A series of reorganizations of the Academy, engineered largely by the new Party people, sought to move the Academy toward applied practical work and especially industrialization, so a new technology division was created and new applied institutes created.

This vast expansion of the research system in the 1930s largely left the universities by the wayside. Not that they were spared; as émigré memoirs make clear, they suffered considerably. In addition to professors being fired, there were new quotas imposed; it was quite common to have political meetings in which Party students would denounce professors for their "bourgeois" sympathies. It also became difficult to get into a university if one came from a professional or merchant family; now those who had been workers, or peasants, or who had Party connections had a distinct advantage. But in the 1930s, Academy institutes also began granting academic degrees, so there developed a dual system of scientific training, split between the universities and state and Academy institutes. The burgeoning of new institutes and their rapid expansion lay at the core of the new system of Big Science that was brought into being, and these institutes could thereby be designed to serve the interests of Big Science. By contrast, the Russian universities had strong and long-standing identities and traditions of their own and, to a remarkable degree, these traditions were able to survive: universities remained centers of excellence, in part because of their marginality in the overall plan.

In the Academy system, by contrast, new norms were in effect, applying the equivalent of factory standards of production, planning, and quotas to scientific research. The vast expansion in staff filled technical institutes with many who were promoted beyond their qualifications because of their politics or class (so-called *vydvizhenie*). Some of these so-called "promotees" (*vydvizhentsy*) had received a good education. But, as Joravsky has pointed out, this hasty, breakneck expansion of personnel resulted in many new research institutions staffed by uneducated, ill-trained specialists.[13] Perhaps the clearest example of this can be seen in the rise of Trofim Lysenko and Lysenkoism.

We can get a sense of how this process took place from the archives of Western scientists who were there. For example, American geneticist H. J. Muller spent the period 1933 to 1937 in the Soviet Union heading a laboratory at the Academy's Institute of Genetics. The materials he saved from that period are revealing.[14] One set of correspondence includes letters from Party officials informing Muller that they would like to replace his current staff and graduate students with Party people. Muller agreed to take them on in addition to (rather than in place of) the geneticists already there. In subsequent years there were understandable tensions between the two groups. As it happened, in subsequent years these Party people from Muller's laboratory became, virtually without exception, supporters of Lysenko.

The imposition of bureaucratic research planning is revealed in other correspondence.[15] One especially telling letter from Muller to the head of the institute's Party bureau in the mid-1930s complains that although he is happy to submit and follow a five-year plan, a one-year plan, and a quarterly plan (as the Academy required), if he was to submit a monthly and a weekly plan (as his correspondent wished) the laboratory would never get any work done. These materials are informative in a number of respects: they illustrate the power of Party cadres, the ways control was imposed, the growing bureaucratism of the system, and the counterproductive character of attempts to apply industrial production standards even to pure scientific research. It is also clear, from Muller's own official "work plans," how he and others coped with these pressures: filling the next year's "plan" with the publication of work that was already largely completed, he could virtually guarantee in advance that his laboratory's plan would be fulfilled.

In subsequent years, the Terror swept up many millions, among them thousands of scientists, essentially completing the processes started at the beginning of the decade. H.J. Muller himself managed to leave before the purges had claimed him; a number of his closest Soviet colleagues were not so lucky. In 1939, both Lysenko and Stalin were elected to the Academy of Sciences, and newspapers regularly ran letters from distinguished Party academicians calling for the arrest of targeted colleagues. Only the outbreak of war with Germany brought this bloodletting among Soviet scientists to an end.

The Second World War produced an interesting shift. In the surge of patriotism following the Nazi invasion, large numbers of young a political scientists joined the Party; in the 1950s and 1960s, this group would assume an important role in protecting science from excessive political intrusion. The last years of the war reopened relations with Britain and America, and from 1945–1946 Soviet science was briefly resurgent. However, there soon followed *Zhdanovshchina,* a reaction against the "excesses" in literature, art, music, and culture—such as jazz, detective novels, and abstract art—that had come with such Western contacts. *Zhdanovshchina* was administered by (and named after) Stalin's "culture tsar," Andrei Zhdanov, who, interestingly, did not play the same role in science, being a supporter of genetics and an opponent of Lysenko's biology.

But Stalin supported Lysenko personally, and his triumph at the August 1948 session of the Lenin Academy of Agricultural Sciences ushered in the final dark years of Stalinism. Beginning in the fall of 1948 remarkable things happened. Vials of fruitflies were smashed, books and journals were removed from the libraries and some were burned, Lysenkoists assumed complete control of Soviet biology and formed a watchdog committee to oversee the actions of the Academy presidium as a whole. Soon analogous campaigns sprang up in cytology, physiology, chemistry, physics, psychology, and medicine. In the months before Stalin's death in 1953, large numbers of Jewish physicians were arrested for conspiracy in what came to be known as the "Doctors' Plot." Their lives were spared only by Stalin's timely demise.

The post-Stalin period introduced major changes—and the leadership of the scientific community tried to cope with the system that Stalin had created. One of the important effects of the war had been that the physicists in the Academy had gained new independence and prominence, and their importance continued to grow in the postwar period. After all, they were responsible for nuclear weapons, rockets, and ultimately Sputnik—or at least claimed responsibility for them—so they were left more or less autonomous within the Academy. Physicists such as Nikolai Semenov (Nobelist in chemistry in 1956), Igor Kurchatov ("father" of the Soviet atomic bomb), Igor Tamm (a subsequent Nobel prize winner), and Peter Kapitsa dominated the Academy's governing presidium in the postwar decades. Almost all of these scientists had learned their science before 1930, and many had studied abroad in Britain or Germany. With the coming of Khrushchev and the de-Stalinization of 1955 and 1956, when some ten or fifteen million people were released from the gulag, these physicists went into action.

In the 1950s, these physicists used their considerable political weight and their administrative control of the Soviet scientific bureaucracy to try to invigorate the system and assert a new independence for science. On the philosophical front, they orchestrated in 1957 a revamping of Soviet philosophy that left its sociopolitical dimensions intact but denied it any role in the innards of science. Kapitsa's clever rhetoric is characteristic of their tactics: reminding the public in a newspaper article that the Soviet Union would not have had nuclear weapons, missiles, or computers if Soviet ideologists had had their way, Kapitsa declared dialectical materialism to be “a Stradivarius violin—the most perfect of violins—but to play it one must know something about music; otherwise it will sound like any ordinary fiddle.”[16]

The scientific leadership's most successful strategy involved a series of Academy reorganizations aimed at isolating science from ideology and bringing it firmly under their own control. The first reorganization in 1957 involved the creation of the Siberian Division of the Academy and its Science City (Akademgorodok) at Novosibirsk. Spearheaded by mathematician M. A. Lavrent'ev (a friend of Khrushchev's from his Ukrainian days), and couched as a response to Khrushchev's call for economic decentralization, the Siberian division was remarkably different from the standard, Stalinized form of bureaucratic science that Russia had known since the early 1930s. For one thing, it was an interdisciplinary division, involving chemistry, physics, biology, and economics institutes independent of their respective divisions. Second, it was administered by an interdisciplinary presidium of its own that reported directly to the overall Academy presidium. Third, it ran its own educational system, including the Siberian Olympiad (a competition aimed at recruiting talented school children to science) and its own university—Novosibirsk State University—whose faculty consisted entirely of the staff of the Science City. This was the only Soviet university that was not controlled by a government ministry.

In the Akademgorodok, these leading scientists used their organizational clout in an attempt to circumvent and overcome some of the unfortunate effects of the Stalinist system: they cultivated many fields that were still under an ideological cloud elsewhere, including genetics, molecular biology, cybernetics, econometrics. In 1961, in the second reorganization, they tossed many technical institutes out of the Academy and returned them to the appropriate ministries. Finally, in 1963 they completely revamped the divisional structure, isolating Lysenko and establishing a new molecular biology division under the ultimate control of Semenov.

The ouster of Nikita Khrushchev in the “little October revolution” of 1964 did not fundamentally alter the character or structure of the Soviet scientific enterprise. True, with the fall from power of Lysenko's principle ally, his hegemony in Soviet biology ended, textbooks were rewritten and genetics was reborn; but Lysenkoists were not ousted from their posts, and they staged modest periodic comebacks during the Brezhnev decades. The growing autonomy of the Soviet scientific establishment and their taming of Soviet philosophy continued. Under Brezhnev, despite ideological zigs and zags, liberalizations and tightenings, the system continued to grow, the bureaucracy expanded, ideological and Party control continued. Within the Academy, an uneasy equilibrium continued between political appointees and good scientists, but both continued to enjoy the special privileges reserved for the stars of the Soviet Big Science bureaucracy. In short, the Stalinist system of science carried on with its own momentum. Set in place in the early 1930s with ideological fervor and terror, it continued on, now run by technocrats of only modest ideological conviction and willing to use only modest forms of repression.

Prospects Under Perestroika

An era in Soviet life ended with the death of Leonid Brezhnev in November 1982. The following interregnum (presided over first by Iurii Andropov, who died in February 1984, and then Konstantin Chernenko, who died in March 1985) came to a close only when Mikhail Gorbachev consolidated his leadership in late 1986. During this period, the USSR Academy of Sciences was headed by physicist A. P. Aleksandrov, who served as president from 1975; he was replaced by Gurii Marchuk only in 1986. Under Gorbachev, the Soviet Union has experienced a remarkable rebirth of open expression that the world has come to know as *glasnost'*. Such periodicals as *Ogonek* and *Moskovskie novosti* have published uncensored articles on Lysenkoism and the repression of Soviet science that have reopened old wounds. Various individuals and groups have been freer to express their opinions in print, professional disputes have become more public, and old controversies have gained new intensity and candor. But as yet, quantitative change has not become qualitative.

In recent months, as unanticipated events have followed one upon another, Western commentators have been afflicted with a wishful euphoria. Most Soviets I have talked to are more sober. They point out that liberalizations have occurred before: during NEP in the 1920s, and just after Lenin's death; just after Stalin's death in the mid-1950s; just after Khrushchev's ouster in the mid-1960s; and now after Brezhnev's death and the prolonged interregnum. While Western commentators fantasize about capitalism, democracy, and the end of the Soviet Union, Soviets see a socioeconomic political system falling apart with nothing to replace it. Soviet policy-makers indeed face a daunting reality. The current system is stratified and bureaucratic, filled by political connection and maintained by privileged access to increasingly scarce resources.

Given the past, the effects of the new democratizing trends can be unpredictable and unsettling. An example is provided by recent events at an institute whose history I have studied—the Institute of General Genetics in Moscow, a lineal descendant of a collective that saw some of the most brilliant and most troubled events in Soviet science. Built around the group created by Filipchenko in Petrograd in the years immediately after the Revolution (a group that included Dobzhansky), the institute became the scientific base of Nikolai Vavilov and was where H. J. Muller worked in the 1930s. Following Vavilov's arrest it was taken over by Lysenko, and it became his base in the Academy of Sciences until it was reorganized in 1965. In its new form as the Institute of General Genetics in Moscow, directed by Nikolai Dubinin, the institute was an amalgam of Lysenkoists and their geneticist victims. After Dubinin forbade the study of human genetics and attacked colleagues who studied it elsewhere as representing "an alien ideology aimed at crushing the human personality," he was eventually removed from his directorship by the presidium in 1981, but nonetheless retained his laboratory at the institute. With the coming of *glasnost',* he denounced the new institute director as the head of a "Zionist clique." As an accommodation, the new Academy president allowed Dubinin's laboratory to "secede" from the institute administratively, while retaining one of its four floors; meanwhile, laboratory technicians quarrel in the building's single stockroom over whose equipment belongs to whom.

With the coming of new laws concerning democratization some two years ago, new complexities emerged for the scientific institutes. On the basis of an official ruling, directors of scientific institutes were now to be elected by the staff—with the Party committee running the proceedings in most places. The first balloting at the Institute for General Genetics, for example, saw the nomination of several dozen candidates; many votes and committee meetings later, the selection was reduced to two. The election led to a 49 percent to 51 percent split; when the losing side protested that this was not democratic, a new ballot was held, and this time the results were reversed: 51 percent to 49 percent. As a way out, the Academy proposed that the loser could be given one of the remaining three floors as an administratively independent laboratory (thankfully he demurred). This is a rough account told to me by people who were there; if even part of it is true, the Academy has some interesting times ahead. As recent elections and reelections to the Soviet parliament have made clear, the Academy remains a deeply divided, sprawling, bureaucratic "empire of knowledge" (in the apt phrasing of historian Alexander Vucinich). In Leningrad, there have even been moves afoot to form a new, "real" Academy to replace the old.

Given the pace of recent events, it is difficult to discern any trends that would allow us to forecast even the shape of Soviet science and technology in a few years time with any certainty. In such a setting, it might seem that history is a useless guide; however, I think it may well prove to be by far the most useful one. Historians know of the extraordinary breadth and interconnectedness of the Russian intelligentsia; current events suggest that it is alive and well. The career patterns of individuals involved in current scientific debates suggest that intellectual and scientific networks dating from the 1920s and earlier have endured, tested and tempered by war and repression. Such personal human networks—formed by "old school ties," extended families, work settings, and common interests—span diverse institutions and disciplines, connecting them in ways that cannot be seen in organizational charts or the published "paper trail."

We have tended to associate the Soviet scientific community with the move for human rights, democracy, and social reform. Certainly some scientists have played a leading role—notably Andrei Sakharov. And it is certainly true that the Soviet scientific leadership was able to make important contributions to the autonomy of their enterprise in the 1950s. But this picture, if not totally inaccurate, can be profoundly misleading. Scientists enjoyed disproportionate success precisely because they were specially privileged—in status, income, and autonomy—and they enjoyed their privileged position because of their contributions to the vital interests of the state: nuclear fission and fusion, bombs and rockets. Their greatest successes on behalf of their own values came as a result of their privileged access to political leaders, their unique contributions to Soviet-style Big Science, and their ability to manipulate its centralized, bureaucratic structures from the top.

Modern science is Big Science; but Big Science Soviet-style was created under Stalin in the 1930s, and it retains the characteristics he gave it. Soviet scientists have never experienced a kind of Big Science that was not politically controlled, statist, centralized, bureaucratic, and relatively isolated from international science. They and their successes are, to a large extent, creatures of the Stalin-Brezhnev system, a system whose future is now uncertain. Recent studies suggest that the reactor at Chernobyl, the disaster there, and the cover-up that followed were also largely a product of Soviet-style "big physics." And despite national economic hardship and Soviet military cutbacks, there have been no cutbacks in science-related military research activity, including the space program and the development and modernization of missile and warhead technology.

It is hard to escape the inevitable conclusion that things cannot go on as they are. Vast quantitative growth in the Soviet scientific enterprise has yielded no corresponding qualitative change—not a positive one, at any rate. If anything, the vast quantitative increases in the number of scientists, engineers, research institutes, and funding appears to have resulted in lower quality, encumbering the current system with a massive scientific and technical bureaucracy. And despite a half century of dedicated efforts to link science and production, following the Marxist dictum of "the unity of theory and practice," today theory and practice are more distant than ever. In the application of science and technology to production, the Soviet Union trails not only North America, Western Europe, and Japan, but also much of Eastern Europe and the Pacific rim.

What options are open for Soviet science? Until the Soviet economic system is fundamentally reformed, it seems likely that the continued successes of Soviet science will continue to depend on its privileged access to the "high-tech" machines, devices, chemicals, and computers on which modern science depends. But special access to such technology by Soviet scientists may deny these resources to other sectors of Soviet society sorely in need of them and lacking the hard currency required to buy them. Nor should we expect too much from democratization, because Soviet-style Big Science encompasses vast numbers of institutes staffed by many people who won their posts through political, Party, or personal connections. Administering these institutes by internal elections of all staff members promises to produce the kind of politicization and disorderly confusion that may make good science hard to do.

Given the history of the Soviet research system, it may be that universities will hold the greatest promise. Although beset by Party and politics after 1930, the universities were largely left out of the vast bureaucratization that accompanied Stalinist construction, and they were able to remain centers of tradition and quality. And here we may be able to help. Under Gorbachev more Soviets are traveling to the West. As in earlier times, however, they continue to be well along in their careers; to some extent, short-term foreign travel is still being used as a form of reward for years of cooperative service. The most useful form of exchange, it seems to me, would be for the younger generation: graduate students who could spend enough time in Western Ph.D. programs to absorb the culture of Western science, to breathe its atmosphere and learn its conventions and values, to form the professional international networks at a young age that will be so important as their careers in Soviet science mature.

Can the Soviet scientific community draw on its pre-1930 traditions and historical experience to effect its own *perestroika* and fashion a new kind of Big Science Soviet-style? I do not know, but, like my Soviet colleagues, I am more hopeful than optimistic.

NOTES

1. The group included J. D. Bernal, J. G. Crowther, J. B. S. Haldane, and others. See Gary Werskey, *The Visible College: The Collective Biography of British Scientific Socialists of the 1930s,* New York: Holt, 1979.

2. Associated with Michael Polanyi and Karl Popper, the "freedom of science" movement exercised an important influence not only on science policy in the United States, but also on the then-emerging fields of the history of science, the philosophy of science, and the sociology of science.

3. The sense of panic is vividly described in James R. Killian, Jr., *Sputnik, Scientists, and Eisenhower: A Memoir of the First Special Assistant to the President for Science and Technology,* Cambridge, Mass.: MIT Press, 1977.

4. See Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age,* New York: Basic, 1985.

5. As American biologist L. C. Dunn noted after a trip to Russia: "The problems frequently and the mode of attack nearly always are quite different from those in other countries and where they have followed an influence from abroad (as in the Drosophila work) they have given it a direction and a method that is peculiarly local or Russian." "Aside from this peculiarity," he added, "they are nearest in spirit and sympathy to the American type" (L. C. Dunn to Hutchison, Berlin, 2 November 1927, pp. 2–3).

6. See, for example, Loren R. Graham, *Science, Philosophy, and Human Behavior in the Soviet Union,* New York: Columbia University Press, 1987; and the review by Valentin F. Turchin, "The Exclusion Principle," *Nature,* No. 331 (7 January 1988): pp. 23–24.

7. For a sample, see Zhores A. Medvedev, *The Rise and Fall of T. D. Lysenko,* New York: Columbia University Press, 1969; Mark Popovsky, *Manipulated Science: The Crisis of Science and Scientists in the Soviet Union Today,* Garden City, NY: Doubleday, 1979; Mark Popovsky, *The Vavilov Affair,* Hamden, Conn.: Archon, 1984; Raissa Berg, *Acquired Traits: Memoirs of a Geneticist from the Soviet Union,* New York: Viking, 1988; and Daniil Granin, *Zubr,* New York: Doubleday, 1990.

8. This moralistic polarity has affected the treatment of even obviously "gray" careers. For example, A. I. Oparin pioneered studies of the chemical origin of life, but he also helped Lysenko destroy Soviet genetics (see Mark B. Adams, "Alexander I. Oparin," in *Dictionary of Scientific Biography,* Supp. 2, New York: Charles Scribners' Sons, 1990. According to one school of thought, Oparin's contribution to the origin of life will be everlasting, whereas his support of Lysenko is ambivalent and not worth dwelling on; according to another, Oparin was an opportunist hack whose contributions to the biochemical origin of life were either faked or insignificant.

9. Nikolai Mikhailovich Lisovskii (1854–1920) was a distinguished and innovative Russian bibliographer. His classic work, *Russkaia periodicheskaia pechat 1703–1900* (Russian periodical publication 1703–1900; St. Petersburg, 1895–1915), was a massive and informative index of all Russian periodical literature. He also graphed the totals, pointing out that "scientific and technical" forms of publishing began a rapid expansion in the period 1865–1885, far outpacing literary, philosophical, social, and others forms of publication. Although rarely if ever credited in Soviet literature as a founder of *naukovedenie* (science studies), Lisovskii anticipated by a half century some of the approaches pioneered in the 1960s in America by Derek Price.

10. For an excellent discussion of the difficulties facing Tsarist censors, see Daniel P. Todes, "Biological Psychology and the Tsarist Censor: The Dilemma of Scientific Development," *Bulletin of the History of Medicine,* Vol. 58 (1984), pp. 529–544.

11. See Derek Price, *Big Science, Little Science,* New York: Columbia University Press, 1963.

12. See Mark B. Adams, "Measurements of the Growth of Russian Science," manuscript, 1965.

13. See David Joravsky, *The Lysenko Affair,* Cambridge, Mass.: Harvard University Press, 1970.

14. H. J. Muller papers, Lilly Library, Bloomington, Indiana.

15. *Ibid.*

16. On development during this period, see Mark B. Adams, "Biology After Stalin: A Case Study," *Survey,* Vol. 23, No. 1 (1977/78).

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Great Britain

RESEARCH AND BRITISH UNIVERSITIES

Sheldon Rothblatt
University of California

As in the United States, universities and colleges in Great Britain developed historically as teaching institutions. That generalization equally applies to universities in England, Scotland, Ireland, and Wales, as well as the universities of the Empire and Commonwealth, influenced by home models. Universities and colleges existed to educate a clerical and governing elite. Later they were places for professional training. Some degree of specialism is required in the second instance, but not necessarily research or the forms of original inquiry associated with the word "research."

Until late in the 19th century, British universities provided little encouragement for research, irrespective of specialism. This does not mean that discoveries could not be made, only that an incentive system barely existed. Academic careers were made in teaching and administration. In Scotland, which did not have a collegiate tutorial structure like Oxford and Cambridge, the professoriate was hampered in research because their proteges were so young, only of high school age. The higher learning meant little to them. For centuries, therefore, ambitious scholars and scientists sought careers outside universities, being supported by patrons or learned societies, popular lectures or private wealth, and, in the first half of the 19th century, by a limited amount of government assistance, usually for projects of a technical or practical character: the design of ships' hulls, agricultural improvement, geodetic surveys, armaments, lighthouse construction, food processing, weights and measurement, mining and manufacturing. Hospitals and medical schools supported an interesting amount of research. This pattern is very similar to what obtained in the United States at the same time. And both nations had "liberal" governments, that is, the prevailing political philosophy favored private initiative over State support and possible bureaucratic interference. In other words, support for research, including original research, existed outside the universities, but it was *ad hoc* and unpredictable and geared to practical results not discovery.

Despite the heavy orientation towards teaching that prevailed in the universities and colleges of both English-speaking countries, researchers would have preferred and did in fact prefer to be in universities rather than in other institutions for a number of important reasons. Universities, especially those of Britain, were noted for their history of self-government, periodically intruded upon by royal and ecclesiastical authorities. Endowments, especially at the oldest foundations of Oxford and Cambridge, were plentiful and normally adequate for the levels of scholarship and science then prevailing. The libraries were splendid and rich in classical and theological materials. In other words there existed, or existed potentially, an environment of relative freedom, leisure and flexibility conducive to the work of independent investigators and populated with a certain critical mass of educated and like minded persons.

The trick was to adapt the structure of British universities to research and unite research with teaching. New universities, for example London or the Victorian "redbrick" universities and university colleges of the provinces, could be adapted to research from the outset, although this did not occur with the ease which this suggests. New universities are concerned with legitimacy and status, and these can hamper innovation and experiment. Nevertheless, the senior universities were harder to influence, especially since the famous reforms of the period 1850–1880 actually strengthened their teaching structure. But gradually the research mission found a place alongside teaching, the result of a combination of public pressure and a movement for change from within. German research models were certainly influential. Equally important, however, was the salient change in secondary education which sent better educated students to the ancient universities, permitting young scholars and scientists smitten with German notions of higher education to teach at a more advanced level and to excite young minds with the new learning, the "knowledge revolution" of the later 19th century as it is sometimes called. Yet we must not exaggerate the extent to which research challenged teaching. The two were not generally considered incompatible one hundred years ago, and today the British universities are still noted for the excellence of their teaching, which partly explains why devoted researchers contend for professorial chairs, which provide more time or at least greater scope for creative activity.

The Muse of History works in devious ways. One particular feature of the teaching structure of British universities proved to be of special value in opening the door to research. The development of the single-subject honors degree, which in modified form travelled north from England to Scotland in the course of the 18th century, eventually became the dominant mode of instruction and examining in the redbrick universities and in most of the post Second World War foundations. The undergraduate degree in Britain, following a European pattern generally, simply became far more specialized than the American baccalaureate. The specialized degree allowed teachers the opportunity to become more specialized themselves. In America, a radically different path was followed. The undergraduate degree remained unspecialized, and even with the introduction of majors continued to remain relatively unspecialized. Furthermore, the comparatively poor quality of American secondary education, especially American mass secondary education, sent students to the universities who were not as well-prepared as their British counterparts. Thus was fastened onto American higher education a concern for remedial education that has continued to be a difficulty. In the United States school and university overlap in function, indeed, the words overlap semantically. The way out for a new generation of American scholars and scientists coming of age was the creation of the Graduate School. In Britain the Graduate School is a relatively late phenomenon, and the pursuit of higher degrees really only became common within the last forty years. A first-class bachelor's degree (the equivalent in Scotland is a master's) was long considered sufficient qualification for a career in high-level teaching and advanced work.

Today all of British higher education—the universities, the polytechnics and the technical colleges—are essentially public institutions, receiving assistance from the State or local authorities. There is a nominal private sector, the University of Buckingham, an undergraduate university college founded in our own day. Buckingham is too poor to support research, especially research in the sciences. Oxford and Cambridge received no State assistance until a small grant was given to the Cambridge medical school just before the First World War. The civic universities were supported largely by fees, municipal contributions, and in a few cases, handsome endowments, but they were undercapitalized from the start. London was similarly supported. The Scottish universities have been in receipt of some government assistance for centuries because of special historical arrangements dating back to a time before 1700 when Scotland was independent. Direct State assistance to higher education has grown since the First World War, but especially since the end of the Second World War. State assistance has accompanied the transformation of Britain from a Liberal to a Social Democratic or Welfare State.

Pressures for State involvement have come from two sources. First is the academic community itself, including the Oxford and Cambridge academic community, which discovered that the customary resources available for the support of scholarship and science were inadequate for Big Science. It was no longer possible to do science with bailing wire and prisms. We now know, thanks to the inquiries of the University of East Anglia historian, Michael Sanderson, that prior to World War One there were scientists in the University of London who undertook secret research for the steel industry, and the professors in the civic universities had long sought the support of industrialists and industries in their regions.[1] But British industry in general ceased to maintain close ties with the universities, preferring in-house research, and the academic community turned increasingly to the State, where, for historic reasons, their connections were strong. The second source of pressure for State involvement is war. Both world wars demonstrated the relationship between science and applied science and brought the universities and the State into partnership.

Until this year, that partnership was symbolized by a committee of the Treasury called the University Grants Committee (UGC), founded in 1919. The UGC was transferred to another ministry, the Department of Education and Science (DES), but is now being replaced altogether, by a wholly new body called the Universities Funding Council, whose composition is more broadly-based than that of the UGC. The UGC was essentially composed of members of the academic community who dispensed a block government grant to the universities with almost no questions asked. The grant was distributed in support of teaching and for other operating expenses and was received from the government on a quinquennial basis, allowing plenty of lead time for planning. It is not generally known—that is to say not easily discoverable—how much of the block grant has in the past gone for support of research since the published figures are not disaggregated. Until a few years ago the reign of the UGC could certainly be regarded as the Golden Age of University-State relations. The guild conception of academic life prevailed. University autonomy was respected, and the universities customarily received whatever they requested. In a special way, the alliance or partnership between the State and the universities dates back to the 19th century. The don and the civil servant were both drawn from the same social stratum in society and received a similar education. They moved in common social and intellectual circles, and their children intermarried. This coziness has come crashing to an end.

The UGC is one half of the basic government support system for university-based research. The other half is the system of government-funded research councils. These receive their income from the Department of Education and Science, which also gives grants directly to universities, but it is certainly possible for income to be derived from other ministries as well, such as the Department of Agriculture or Environment or Energy or Trade and Industry. Two research councils, concerned with medicine and agriculture, were established before the Second World War and represent traditional areas of State concern. Three others, the Science and Engineering Research Council, the Natural Environment and Research Council, and the Economic and Social Research Council were formed under the Labor Governments of the mid-1960s. (There are earlier precedents.) Universities also receive research grants from private foundations, but this sector is not nearly as strong as in the United States. Money can flow into the hands of academic researchers from nationalized industries in the form of commissioned research, although this opportunity is being lost by the privatization policy being applied by the current Government. (Of course new opportunities may arise on the same basis.)

The system of governmental support for research carried out in universities has from the outset been characterized by decentralization, a similarity with the United States. The numerous departments, committees, boards, advisory bodies and councils through which money passes have made the path of such funds often difficult to trace or disentangle from other budget items. A decentralized system also raises questions of project coordination and often produces charges of duplication of effort. But decentralization also means flexibility and provides alternatives, for when sources of support are choked off at one level, they may continue to flow at another. A decentralized system also allows for a certain balance, if not exact balance, between research and development in the R&D budget. As in the United States, the British universities are the primary source of what for want of a better name is called “basic research” or “pure research,” and a decentralized research support system very likely allows for greater scope by the researcher or research team in defining a problem and its methods than a more *dirigiste* agency.

But that is seeing the issue from the standpoint of the researcher and from the perspective of the academician, who, in ideal fashion, view discovery as an addition to knowledge with possible but not predictable practical application. The research support system that grew up in Britain in the first half of the 20th century has certainly favored the researcher and the classic research ethic. However, signs of a re-evaluation of research policy were already apparent in the last Labour Government, and it has to be concluded that at the moment at least central changes are occurring and have occurred in the government support package.

Until recently there has not really been a coordinated or central “research policy” in the United Kingdom. The shared assumption was that basic research could more or less be left to universities, and it was the responsibility of the UGC and the research councils to continue support for established research projects and decide on funding for new ones. It was generally assumed that funding agencies would more or less limit their interference to marginal matters. The questions of priority research or targeted research and the ideal balance of “R” to “D” were not really discussed, although Lord Rothschild, in a famous report issued in 1971, reflected on these matters. But in the late 1970s the formulation of science policy in relation to government income and expenditure began to generate serious reconsideration, and the broader question of Britain's economic competitiveness entered the picture. The DES science budget had in fact been declining since the late 1960s, falling from a high of 13 percent per annum in 1966 to about 4 percent in 1972–1973. Since then through 1988 the DES science budget has been held roughly level. However, DES support through the UGC has fallen, as has commissioned research by the various government ministries, excepting Defense. The UGC began “rating” academic departments on their research output in order to find a utilitarian measure to account for the expenditure of pounds sterling.

At every level of support, spending plans are now undergoing much closer levels of scrutiny, and the watchword is much greater selectivity in funding projects. Apparently even the best scientists are being given less freedom to manoeuvre. Symptomatic of new trends towards centralization is publication of the Annual Review of Government Funded R&D. This valuable document first appeared in 1983, a Product of the Cabinet Office itself.[2] We may also be witnessing the emergence of a professional class of university administrators on the American model, wherein decision-making is shifting from academic senates and courts to vice-chancellors and registrars. The current slogan is that research should have practical application and generate more wealth, that it should be "applied" or "strategic" (long term goals with short-term flexibility) and subject to central bureaucratic attention.

We will shortly have a better estimate of how current thinking about a "science policy" is actually being carried out. There are several early returns, however. Universities are forming consortia with other universities, with polytechnics and with industry in competing for government money. In some instances universities may be benefitting, as in the transfer of work from in-house ministerial or research council institutes to university departments, especially in agriculture and environmental science. Greater central control is represented by short-term contracts, single grants in a given area of investigation and the search for measurements of effectiveness in addition to the classic peer review process, e.g. output measurements.

Unlike the UGC (that is, the UGC before the 1980s when the hardening economic situation turned it into an antagonist as much as a supporter of universities), the new Universities Funding Council will contain representatives of industry, as do the boards of the research councils and other major science advisory units. So the dons no longer have an exclusive or even an upper hand in determining how research money is to be spent. Furthermore, the market orientation or at least the talk of using the market to discipline universities has led the Conservative Party Thatcher Government to adopt a new policy regarding the funding of universities. Instead of providing them with long-term support, covering all or nearly all of their varied activities, the present Government will provide universities with only a portion of their budgetary requirements, asking them to seek outside support to round out their income. The research councils themselves have been seeking outside support.

Ten years ago no one could have foreseen the revolution in attitude towards universities and the changes in the support system that are nearly in place as 1990 rolls around. The primary impetus for change was the charge that Britain was not meeting its foreign competition, that its corporate leadership was elegant but not professional and that its labor supply was restricted by strikes, radical shop stewards and outmoded trade union practices. Economic difficulties provided an opportunity for some serious questioning of the role of universities in promoting the national welfare at all levels, and revived charges going back to the past century that the universities ignored applied science and technology. These charges may not be altogether correct. It is important to look at the other end of the equation and also ask whether industry is interested in or able to absorb and develop as well as support the findings of university research. The evidence seems to say that British industry between the wars also became dependent upon state sources of capital for innovation, and many sectors of the economy lost their initiative and incentives. Universities do not customarily engage in product development. Indeed, in the public university sector in the U.S. such activity is regarded as falling within the area of conflict of interest. But the best statement of this matter that I have run across was made by a distinguished engineer about a decade ago who, after pointing out that labor mobility, management skills, interest rates, taxing policies and so on are critical factors in changing lab science into products, wrote that "the 'technological plateau' of a wide range of unspectacular but exacting technologies which permeate important industries is as least as important as the few 'dazzling peaks' which arise in a few small sectors."[3] The historian Michael Sanderson, who has done the most to inquire into the working relations between universities and industry in Britain since the turn of the century, has in fact found much to praise on both sides.[4]

Nevertheless, Britain's declining competitiveness in the 1970s, as measured by a great many economic indicators, demanded a fresh look, and both major political parties talked about improving industry's use of scientific information. The Thatcher Government applied the whip. To use a broken image, the whip is to some degree ideological. The present government believes that market forces *a l'Americaine* should play a larger role in the generation of wealth. But the Thatcher Government has not yet relinquished full control of the university sector as market discipline requires, claiming that guidance is necessary while the transition to a more competitive educational system is taking place. To effect that competition, the Government has abolished tenure, suggesting that an anxious academic is a more efficient academic, and it has subjected the university sector to a severe diet of budget cuts, forcing early retirements. The American universities have been among the beneficiaries, since a brain drain of unknown dimensions is currently taking place.

There is no doubt that historically the quality of British research has been high. The excellence of British science and scholarship is attributable to the excellence of their educational system, which has been elitist but also meritocratic. Staffing ratios have been twice as good as those obtaining in our own public sector. Entrance to universities has been highly competitive, and the winners in the race for life chances have been well supported in their education, not knowing the struggle that has led so many American students to part-time work. Remedial education has been nearly nonexistent, the drop-out rate from universities is negligible, the completion rate exemplary. Consequently, the intellectual and academic payoff is very high. These conditions have favored quality research, although there has in the past been some criticism that the single-subject honors degree made intellectual innovation more difficult since the curriculum was dominated by set books and papers. Such criticism, however, is very difficult to prove, although it makes for good political copy.

The Thatcher Government, while engaging in its slenderizing policy, has argued that the universities were filled with unproductive faculty, and it was from this criticism that the UGC derived its interest in measuring output. But again, there is no real evidence that the charge is warranted. Whether the changes that have been introduced in the 1980s will promote a lean but excellent system and a more productive economy is not a prediction that can be made, yet an offshore observer might reflect that quality is hard to obtain under any circumstances, but that excellence is easily compromised. A careful government might wish to avoid de-stabilizing a system with a proven track record in original research.

Given the polemical environment in today's Britain, it is often forgotten that we are actually witnessing the second assault on the British educational system, for the first one came from a Labour Government which abolished nearly all of the historic and very fine local grammar schools in the 1970s, replacing them with "comprehensive" high schools on an American model. The inspiration behind this change was social, not academic, for the grammars had earned an excellent reputation as feeder schools for universities; but because access to them was governed by competitive entry, they were accused of being needlessly exclusive. The results of that change appear to be mixed, insofar as improving the life chances of working-class children is concerned. As for the wealthier families, they have resorted to the independent educational sector, within which are the vastly prestigious so-called “public”—privately endowed—boarding schools.

Social justice and academic excellence do not always work in tandem. Access to universities has improved, largely because of the recommendations of the Robbins Committee of the 1960s that many new universities be created. But from all accounts, entry of working-class children into the universities is still disappointing. And there is no system of transferring from a less competitive sector of higher education to a more prestigious one for late bloomers, nor are there signs that this particularly important feature of American higher education is likely to be widely adopted, although experiments with American-style curricular modules and credit-units are going on, mainly if not exclusively in the polytechnics.

Achieving a balance of objectives is very difficult for any society, as we have painfully learned. In the United States, we possess an educational system in which many of our citizens are either poorly educated or not educated at all, and many of our universities are filled with young people whose standards of achievement do not match up with those of their counterparts abroad. We rely on certain portions of our private sector of education to keep the standards up, but they, of course, are not in the business of mass education. Nor are they the only source of our future research talent. We are at the moment experiencing a shortage of high quality students in our graduate science programs and are relying heavily on foreign-born candidates in certain important fields. So we too are going to have to make important choices.

Mention should finally be made of one of the greatest uncertainties of all with respect to the British science and research effort, namely, the coming of a United States of Europe in 1992. At this time no one knows what kind of federal government will emerge in Brussels and how the new arrangements for governing will affect national sovereignty. All of the factors that go into determining a nation's science policy—taxing and funding strategies, support for industry, support for high technology, the excellence of research training, the quality of lower forms of education, the general structure of incentives and rewards for competitive achievement—may have to be reconsidered from scratch if a One Europe dream becomes a reality.

NOTES

1. Michael Sanderson, “The University of London and Industrial Progress, 1880–1914,” *Journal of Contemporary History,* Vol. 7 (July–October 1972), pp. 243–262.

2. British Cabinet Office, *Annual Review of Government Funded R&D 1983 and 1984.* Her Majesty's Stationery Office, 1984.

3. Sir Ieuan Maddock, “Science, Technology and Industry,” *Proceedings of the Royal Society of London,* Vol. 345, No. 30 (September 1975), p. 325.

4. Michael Sanderson, *The Universities and British Industry, 1850–1970,* London, (1972), p. 387.

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Federal Republic of Germany

TRENDS IN THE TWENTIETH-CENTURY GERMAN RESEARCH ENTERPRISE

Alan D. Beyerchen
The Ohio State University

Introduction

A good way to begin our discussion is to make two pairs of observations. The first pair of observations relates to scale—not so much Germany's scale, but Japan's. Approximately half the size of the United States in population, Japan has about 120 million inhabitants. The Federal Republic of Germany has approximately 60 million. In fact, it would take the Federal Republic of Germany, the East German Democratic Republic, and a sizeable portion of the United Kingdom to equal one Japan. I would like to put that in relief, at a time when we are becoming increasingly conscious of the value of human potential.

In terms of scale, the Germany of today is not the Germany of legendary academic yore. We hold the Federal Republic of Germany today often to the same standards that we came to expect for a Germany that was significantly larger—in, say, 1910. Imperial Germany occupied much more of the map, but the population in the course of the 20th century has been pretty much constant due to the truncation of territory. There were about 60 million Germans in 1910 as well, at a time when there were about 90 million Americans. So Germany's relative size has dropped from about two-thirds of America's population to about one quarter.

The second pair of preliminary points has to do with paradoxes that loom large in the German mind concerning both the threat and the richness of fragmentation. One level of fragmentation is political and economic. The Germans are constantly aware of this. The memories of the Thirty Years War of the 17th century and the Napoleonic wars of the early 19th century have left Germans with a sense of vulnerability as inhabitants of the land in the middle. This land occupies a crossroads between East and West that can all too easily become a battleground in which the various parties fight each other to the last German. Out of this position, however, also comes a rich heritage of diversity and cultural achievement, as the Germans have exchanged goods and ideas with each other and with the peoples around them. There is a fierce resistance in Germany, even today, to the idea of homogenization. People protect their local customs and dialects and take pride in them.

This legacy of political fragmentation—remember that as late as 1800 there were still over 300 different principalities and powers in the German area—underlies the intricate federal-state relationship that regulates and nurtures the veritable forest of research institutions that dot the German landscape. In many cases the states were quite independent realms. They were sovereign countries, so that states' rights, especially in cultural matters, are more deeply imprinted upon German life than upon American.

There is also another kind of fragmentation, a social fragmentation. It plays out as the legacy of the cleavages between the landed aristocracy, the middle class in cities and in industry, and the lower classes in the countryside and in the factories. The threat of political change in 19th and 20th century Germany has predominantly been feared as coming from below, rather than from rival factions among the upper classes. That lower element has been represented to a very large extent by the Marxist Social Democratic Party of Germany, the SPD. The educational system has long reflected the cleavages along what has been called

Germany's "most important sociopolitical frontier," that is, between the upper and middle classes on one side, and the lower classes on the other.[1]

But there is richness here too, in this social fragmentation. The boundary has been firm enough so that a prestige system has come to exist on both sides of it. Rather than working just to leave the lower classes, laborers have drawn upon the craftsman tradition to compete with each other for achievement and a sense of accomplishment. This has much to do with the fact that the pursuit of excellence in Germany has not been limited to university-trained elites, but has occurred within each layer of German society. Excellence on the job shop floor is every bit as important as in the Nobel Prize calibre laboratory. One relevant consequence is that managers trained in engineering or the sciences of ten feel they should be able to prove the mettle of their own skills in front of workers who have high standards against which to measure performance.[2] A different implication has been the high level of consciousness among government officials of the need to consider the social impact of technological change. Domestic peace has been a very high priority for the Germans in positions of authority.

Research Institutions in an Export Environment

The research that came to fruition in the pre-1914 era of export posture had a long tradition. The research enterprise had been initially characterized in the 19th century by the academies of science, which were fundamentally 18th century phenomena. They were soon surpassed by the older universities, which underwent major reform in a movement led by Wilhelm von Humboldt at Berlin University around 1810. His goal was to marry teaching and philosophical inquiry, which produced the much vaunted notion of German *Wissenschaft,* which we often translate as "science," but which I prefer to translate here as "scholarship," because it does not connote just the physical or natural sciences.

Philosophical inquiry mated with teaching produced a fundamental challenge to the older faculties of medicine, theology, and law. As the new model spread in the early 19th century (keep in mind that all German universities have been and are state institutions), philosophical inquiry became the heart of the humanistic research tradition. That tradition has been the basis for the university near-monopoly on the research Ph.D. degree that persists today. Mathematics and the natural sciences ultimately set the character of the changes, as the research "institute" emerged as virtually a fief of the professorial chair in a given university. I say *the* chair because there was one full professor of mathematics, one professor of chemistry, one professor of physics or astronomy, etc. These people were selected from a pool of researchers who had finished a second research project, one beyond the Ph.D. Since the appointment process essentially had the resources of the entire state behind it, first-rate researchers could demand that imposing conditions be met in order to accept an appointment. Research in the physical sciences, or in medicine, however, often had utilitarian impact. In the face of criticism from their humanistic colleagues, scientists usually extolled a pure science ethic which bolstered their claims of the divorce between basic research and application.[3]

The pure science rubric, however, along with its justification, was under pressure from extra-university research institutions in the late 19th century. The chemical industry, for example, produced laboratories that very effectively availed themselves of academic expertise and personnel. By the end of the 19th century they were doing basic research of university calibre. The institutes of technology, the *Technische Hochschulen,* were engineering schools that by 1899 had acquired formal co-equal status with the universities. There was a proliferation of government laboratories; for example, the institutes for Robert Koch and Paul Erlich were set up as medical research laboratories with a basic research impetus involved in them, but with work too applied for the university pure science ethic. Extra-university institutes were justified in very explicit terms by men such as Werner von Siemens, who was involved in setting up a national bureau government of standards. At one point in the debate about funding he argued:

> *In the present and vigorously conducted struggle of peoples, the country that opens new paths and creates or enlivens important branches of industry has a decisive superiority. . . The patronage of natural scientific research is thus in eminent degree an advancement of the material interest of the country.*[4]

One could not get much clearer than that.

Chancellor Otto von Bismarck actually got engaged in some of these funding matters, apparently because he had come to share the view that enhanced technical prowess led to increased national wealth. He needed that wealth to help pay for innovative social legislation that was designed to undercut the appeal of revolutionary Marxism among German workers. Although Bismarck's commitment to social legislation was tactical and paternalistic, Siemens and others had more profound ideas. Siemens announced that:

> *. . . engineering based on physical science would increasingly obviate the need for demanding bodily labor and make material abundance available to all. Consequently, the practical ends of social democracy would be attained without a violent overthrow of the existing order solely by the undisturbed progress of the age of science.*[5]

The issue of international competitiveness became acute as Germany industrialized, urbanized, and experienced rapid population growth. Germany, particularly Prussia, had been a major exporter of grain in the first half of the 19th century. But Russian grain came into the German market more and more cheaply toward the end of the century and American grain came across the Atlantic more and more readily. Due to the costs of artificial fertilizers in intensive cultivation of the land, the price of German grain was rising while the price of grain coming from the outside was falling. After those lines crossed, Germany not only lost its export status, soon was no longer able to feed itself adequately with its own agricultural production. Tariffs were enacted in 1879 reflecting this fact, and were raised higher after the turn of the century mostly to protect Prussian landowners.

It was clear that Germany could achieve economic security only by excelling at export trade. The iron and coal (“first industrial revolution” technologies) and chemical, pharmaceutical, machine tool, and electrotechnology industries (“second industrial revolution” technologies) did exactly that, excelling with a vigor that startled the British, dismayed the French, and set a model for the Americans. These industries were supported by a research enterprise comprising an extensive university system, several federally supported institutes, industrial laboratories, dozens of professional societies and domination of scholarly publication in many fields. The sheer magnitude of the organized German assault on the frontiers of knowledge was awesome.

TABLE 1

	GERMAN RESEARCH INSTITUTIONS	
	(Pre-1914)	
Academies		Universities
	Industrial Labs TH (institutes of technology) Government Labs	
	Kaiser Wilhelm Society (KWG)	
	(1914–1945)	
	German Research Association (DFG)	
Helmholtz	DAAD	Humboldt
	Rockefeller Foundation	
	National Ministery of Education (1934–45)	
	Nazi Four-Year Plan (1936–40)	
	(Post-1945 West Germany)	
	Max Planck Society (Formerly KWG)	
Fraunhofer Society		Stifterverband
	Battelle and AIF DAAD and Humboldt refounded Thyssen and Volkswagen	
	(Ministry for Atomic Energy) (Ministry for Scientific Research) (Ministry for Education and Science)	
	(1972)	
Federal Ministry for Research and Technology		Federal Ministry for Education and Science
	Big Science Establishments	
	Regional Science Parks International Cooperative Projects	

I have argued elsewhere that the key ingredient in the German research success story in this period was not the university system as commonly believed today. Instead, it was the creation of those new institutions intended to stimulate or bypass the institutions moving too slowly for the rushing times. (See Table 1.) Competitiveness was sustained through the institutionalization of a synergistic system that functioned in a very modern manner, blurring the distinctions among pure science, applied science, and technology. In particular, in an organization such as the Kaiser Wilhelm Society erected in 1911, there was a dual legitimation of basic research. The justification was of basic research as pure science when it was undirected, and as applied science when it was directed, even if the same person in the same institute would be doing the same work under discussion. A profound and very useful ambiguity allowed the government and certain far-seeing university professors to extol the virtues of the science-technology interaction when they were discussing financial matters with industrialists or government figures, while stressing the distance of basic researchers from application when addressing the concerns of their more culturally conservative colleagues in the universities.[6]

Research Institutions in an Environment of Autarky

The period 1914 to 1945 was characterized in general terms by the ascendance of autarky over trade as a means to economic security. One can view the entire period 1914 to 1945 the way Winston Churchill did, as a second Thirty Years War with a 20-year armistice separating periods of military combat at both ends. A key German goal in this long siege was delineated in the now infamous September Program of 1914. The goal was to establish a “Middle European Empire” subjugating or exploiting the rest of Europe's lands in order to be able to compete on a world stage with the United States and with the British empire. During the war, university classrooms were emptied. Science and technology were called upon primarily for military research and military application such as munitions production, gas warfare, or *Ersatz* and synthetic materials. As an indication of their fundamentally ambiguous nature, the Kaiser Wilhelm Society's institutes were largely switched over to military research.

The Weimar Republic, which emerged in 1918–1919 and lasted until 1933, faced very serious constraints imposed upon it by the allies. In a combination of treaties and other agreements, Germany attempted in effect to play East off against West in the 1920s and 1930s, leaving itself essentially isolated between the two. Within this context, the leaders of German organized science in the 1920s often referred to science as a *Machtersatz,* as a “power surrogate.” Military and economic might had been toppled, but the prestige of Germany's science continued to stand unscathed.[7]

The rigidities of the university system were also left unscathed in the 1920s. Efforts to open access to women, for example, achieved limited success, and the full professors continued to be dominant. The states continued to have responsibility for science as a cultural dimension of German life and again changes came from outside and around the universities. A number of new science institutions appeared. In particular, there emerged the grant dispensing agencies, such as the German Research Association (which had another name at the time), the Helmholtz Society, the Emil Fischer Society and a number of others, some of which did not last. There were other institutions that were designed to foster exchange programs, namely the Deutscher Akademischer Austauschdienst (DAAD) and the Humboldt Foundation. (The Humboldt's roots went back much farther but it was very important here in the 1920's.) Also, the Rockefeller Foundation's agencies were engaged in fostering exchange and building important research institutes. The Rockefeller people put about $350 million into their Foundation up to the end of World War Two; approximately $47 million of that went to western Europe, about $4 million to Germany. Approximately $400,000 went into one set of institutes in Göttingen alone.[8] The idea was to identify and enhance the best work—the Rockefeller people said they wanted to "make the peaks higher"—and the Germans talked about *Spitzenforschung*.

During the Weimar Republic, professional autonomy was not seriously challenged by the government itself, but the inflation and the depression still erased any confidence in the democratic regime. When the Nazis came to power, they immediately challenged the autonomy and the authority of the professoriate. There was, after all, less need for a "power surrogate" under a regime that fully intended to restore Germany's military might. Dismissals were implemented for persons who were Jewish or otherwise "politically unreliable," as the phrase went. Ideological attacks were launched upon objectivity and the "pure science" ethic as bourgeois frauds that allowed scientists to do whatever they wanted without being responsible for their actions.

The Nazis also attacked basis research as inherently too slow; the new Third Reich was in a hurry to pursue its racist and expansionist goals. Few scientists and engineers emigrated voluntarily. Like professionals in other fields, most made the compromises necessary to continue their work and careers amid the welter of competing Nazi agencies. New professors had to withstand three credential checks: a check of their professional credentials (by the Ministry of Education), a check of their political credentials (by the Party headquarters), and a check of their ideological credentials (by the office of the Party ideology chief).[9]

Scientific institutions reflected the contradictory policies of the Nazi era. A national Ministry of Education was erected in 1934, but it remained weak. The states still wanted to have control over cultural affairs and fought centralization despite the fact that they were reorganized on Nazi lines. A Four-Year Plan to help prepare Germany for war emphasized very important scientific and technological dimensions useful to economic autarky, particularly synthetic materials. This entwined the Four-Year Plan very tightly with I.G. Farben's activities, specifically its projects in synthetic gasoline and *Buna* (synthetic rubber). Technical research was favored over basic in every field by the Nazi regime.

Research Institutions in a New Export Environment

After a difficult initial period, the post-1945 West German environment has again been one of export.[10] Allied occupation in 1945 to 1949 occurred in a time when Germans were living under miserable conditions. Allied occupation meant Allied "exploitation and control" as well, before aid like the Marshall Plan came on line. Exploitation was embodied in programs such as FIAT (Field Information Agency Technical) that sent teams to occupied Germany in order to assess the technical achievements of the Germans by examining patents, looking over machinery, interviewing researchers, and all sorts of things. Operation Paperclip was involved in bringing Germans to the United States. Control was embodied in things such as dismantling of I.G. Farben, or promulgating Allied Control Authority Law 25. This law generally permitted teaching of science and engineering, but specified that only basic research be allowed in most fields and prohibited entirely research in fields such as nuclear physics, rocketry, aerodynamics, and mathematics with importance for cryptography.[11] During this period the universities were de-Nazified. More exactly, Nazi personnel were removed, but the structure was basically left intact. The Kaiser Wilhelm Society reemerged as the Max Planck Society.

Various groups of German scientists tried to determine how to set up a science policy to deal with the increased scale of science. A tension emerged between rival organizations of scientists, some stressing the need for decentralization to keep the government out of decision making. Other groups argued that the government ought to be involved because of the scale of projects, and felt that they would probably be able to control how the government was involved. Gradually, all of this led to the reemergence of the German Research Association as the primary grant dispensing agency. It was largely exempt from federal control for a quite a while, and still retains considerable insulation in professional scientific affairs.[12]

The economic miracle that lasted from 1949 arguably all the way into the 1960s began at a time when the Cold War had already begun with the currency reform of 1948 and the Marshall Plan. With Economics Minister Ludwig Erhard's emphasis on export trade, an economic upsurge occurred. Erhard argued that the key to economic security lay in exports and in his conception of a mixed economy. By “mixed,” he meant a reconciliation of competition and social expenditures:

> *Competition ensures that all advantages which result from higher productivity will eventually be enjoyed. Along the road of competition socialization, in the best sense of the word, of progress and profit is best realized. In addition, personal incentive for higher productivity will remain alive… Prosperity for all and prosperity through competition are inseparable. The former marks the aim, the latter the path leading to it.*[13]

Erhard's conception of a social market economy continues today to provide the framework within which all economic and social issues are addressed in the Federal Republic. In essence, productivity creates the expansion that generates the wealth to meet social needs. International competitiveness and a favorable export trade are once again crucial, and West Germany's exports amount to one-fourth of its GNP. Economic security is now defined in terms of domestic equity and international interdependence rather than rivalry or autarky.

There seems to me a great deal of merit in the argument that the Germans actually made a virtue of necessity with their *Wirtschaftswunder* (economic miracle). Most physical plant had actually survived: contrary to popular belief the destruction figures hardly ever reached 25 percent of the industrial facilities in a given industry. The Allies had basically also blocked or prohibited many new technologies. So the Germans resorted to familiar materials and improved techniques and used existing or restored plant as a basis for generating the capital needed for updating. They had no choice initially.[14]

They thus became the unchallenged masters of innovation in the “second industrial revolution” technologies (such as chemicals, electrotechnology, and machine tools), at both the researcher and craftsman levels. This fit very well with the general German style of technological innovation and adaptation, which has really been more fundamentally “tychophobic” than “tychophilic” (my neologisms meaning risk-fearing and risk-loving) than is popularly thought. The big banks have not offered high-risk venture capital, preferring along with most managers to pursue proven formulas for success—formulas such as excellent craftsmanship, technically proficient management, high quality goods, on-time delivery, and excellent after-sales service.

The support for science mushroomed in the postwar period. Science appeared as the key to competitiveness and, perhaps, once again, prestige. Some organizations of the 1920s had folded, such as the Helmholtz Society, but most persisted or were refounded. There were organizations funded by industry such as the Fraunhofer Society, the *Stifterverband,* Battelle (which does contract research for small corporations) and the AIF (that also basically works for small corporations as a consortium). Organizations for the promotion of scholarly exchange such as the DAAD and the Humboldt were refounded. Private foundations such as the Thyssen Foundation and the Volkswagen Foundation emerged as, to some extent, a replacement for the Rockefeller Foundation that was no longer as heavily engaged in German affairs.

In terms of government activities, a federal ministry for atomic questions finally emerged in 1955 when Allied control restrictions were finally lifted, and conflict immediately ensued between Federal and State governments over the funding of what were called the "Big Science Establishments." (That's one word in German, of course: *Grossforschungseinrichtungen.*) These meant large projects in areas such as nuclear, space, and cancer research, along with a number of others, including data processing. The state governments, however, continued to fund the universities. With billions of marks at stake annually, and the growing perception that the relations between science and technology should be a matter of public concern, science policy has become a matter of hotly contested debate. A coordination network has emerged to adjudicate the fights and advise on policy. The centers of this network are the Federal-State commission that worries about relations between those two sets of funding agencies, and the advisory body of notables called the Science Council, neither of which has been immune from criticism in the fray.

The situation today emerged after 1969, when an SPD government came into power. The Federal Ministry concerned with science had gone through a series of name and authority changes, and finally, in 1972, split into a Ministry for Research and Technology (which includes the Max Planck Society's nearly fifty institutes, the Fraunhofer Society, and various international cooperative projects such as the EUREKA Project) and a second Ministry for Education and Science, in which the German Research Association as a grant dispensing agency is located. Furthermore, the university structure—still funded primarily by the state governments—was altered finally at the end of 1975 to offer enhanced access and to dilute the power of the full professors by lowering student entrance prerequisites, by bureaucratically codifying academic job descriptions, by erecting in some places American-style departments, and by building more universities and other kinds of institutions of higher learning such as teachers' colleges.[15] Student enrollments have, however, nearly tripled since 1975, with over 25 percent of the relevant age group finishing secondary education and taking the requisite exams to go to the universities, versus only about 7 percent in 1968. The results have been emphatically mixed, with enormous teaching loads and erosion of morale driving many of the best researchers from the universities to other institutions.

Over the years, by and large, the relationships among funding sources have remained relatively constant. As a crude approximation, research has been funded 50 percent by government and 50 percent by industry, with science funded five-eighths by government and three-eighths by the private sector. A diagram in one of the reports on German research put out by the government of the Federal Republic divides destination of resources into university research, extra-university research, and economic (i.e. process and product) research of various sorts.

The states provide the bulk of the funding for the universities. The federal government provides little for the universities, but offers most of the funding for the extra-university research institutions (including the Max Planck Society and the Big Science Establishments), and a fair amount for economic research. Industry provides relatively little, although something, to the first two categories, but funds most of the economic research that we might call design and development.[16] With encouragement by the European Community and the national government, municipal governments have recently begun to take an active hand in the erection of research parks or innovation centers, and various European Community cooperative research projects (such as EUREKA) are drawing German industrial and government-funded researchers together.[17]

Prospects

It is appropriate to address prospects for a few moments. First, the implications of the prowess of the Germans in "second industrial revolution" technologies should be considered. Such prowess, seen positively, means that the Germans can go slowly and cope with the social impact of change. The German tradition is really one of gradualism. It goes all the way back to the time of Bismarck's social legislation, which was supported by both labor and business. Viewed negatively, however, the Federal Republic is dependent on markets in countries that need high-quality "second industrial revolution" goods and services. Where are those markets? They lie in Eastern Europe, the Soviet Union, and the Third World. How vulnerable does this make Germany, does it make NATO, does it make the European Community? In a book that has recently come out, a Frenchman has written that the Common Market does not have a European problem facing it in 1992; it has a German problem—the pull eastward, and perhaps even backward, by the Germans upon the rest of the Community.[18]

Developments in Eastern Europe and East Germany since the summer of 1989 have if anything underscored this concern. Some commentators have stressed the initially enormous cost to the West Germans of restructuring the East German economy, but the primary concern here is the relationships among research institutions. Since the early 1970s, the politically dominant East German institution has been the Academy of Sciences of the GDR, which is an amalgamation of the erstwhile Prussian Academy of Sciences and the Russian model of an academy of sciences with a system of institutes. A set of councils has determined policy and personnel allocations for the Academy and the other primary research institutions such as the universities. If Article 23 of the West German Basic Law were ever invoked, allowing an East German *Land* to join the Federal Republic, then the universities and various institutes of technology that predated the segregation of the German states in 1949 would probably be readily assimilated into a unified German research system. If Article 146 were to come into play, rewriting a unified German governmental structure from the top down, the Academy system and councils would become more assimilable than otherwise.

Second, why have the Germans not leaped into "third industrial revolution" technologies? The mastery of innovation of the "second industrial revolution" technology and the consequent unwillingness to depart from successful patterns is only part of the problem. There are other factors. The fundamental prime mover in the first industrial revolution had been steam, in the second was electricity, and in the third is information. Let us consider briefly three key areas that offer insight into how the Germans are doing in information-driven technologies.

In cybernetics and robotics, the Germans have lagged significantly behind the lead of Japan and the United States. The impetus for robots in Japan came from a labor shortage and projected demographic trends for an aging human workforce. In the United States, it has been said that the demand for innovation came from the desire to shift away from fractious blue collar workers to more congenial "steel collar" workers. The Federal Republic has had, thanks largely to government efforts to cope with the social impact of technologies, relatively good labor-management relations. That is what the social market economy constructed Erhard has been all about, providing a positive social context for industrial development. West Germany, too, has faced a labor shortage, but it has solved it with a traditional German method: the *Gastarbeiter* (guest workers). Instead of a robot, there has been a Yugoslav or a Turk on the job.

The computer is another "third industrial revolution" technology. The mathematics infrastructure for computer development is there, certainly, as well as the computer graphics and other innovations necessary for pursuing numerical techniques in nonlinear science, where many important future developments will occur.[19] But perhaps there is something deeper involved here. The "third industrial revolution," as I have said, has information as its prime mover. Initiative information technology perhaps requires the context of a society within which information flows readily, even if that society is closed to outsiders. Germany has seemingly permeable boundaries at its borders. But the internal flow of information has a high "viscosity" level due to a cultural structure that understands all too well that knowledge is power and information is empowerment. We tend to focus on the permeability of legal or cultural boundaries, but this may be less appropriate than looking at the information viscosity within a given society. The USSR and Japan have less porous borders than either the U.S.A. or the Federal Republic, and we tend to lump countries together as protectionist or free-trade. Yet West Germany and the Soviet Union on the one hand and the U.S.A. and Japan on the other have some interesting similarities when seen from the perspective of sluggishness of internal information flow. The Japanese, sensing this, frequently refer to theirs as an "information society."

Biotechnology also belongs to the "third industrial revolution." Two historical streams form a cultural confluence that impedes German developments, despite considerable government funding and plenty of scientific expertise. One is a powerful ecological movement that responds to genetic technologies as a form of industrial production that threatens the environment. The other is the memory of the pre-1945 eugenics movement discredited by its prominence in the Third Reich and by Nazi efforts to exterminate supposedly inferior and selectively breed supposedly superior "races." The result is that the context for biotechnology is likely to remain restrictive for some time.[20]

The Germans are slow to begin changing, but once they do, their industriousness and thoroughness make them very formidable competitors. I think they will become so. Although for a time their energies and investments may be absorbed Eastward, there is perhaps an interest for the U.S.A. and the West in general to wean the Federal Republic from its "second industrial revolution" technologies and the markets to which the Federal Republic is most attracted as a consequence. Such pressures may come into play.[21]

The German style of research organization seems unwieldy and nearly organically overgrown as a thicket of institutions and agencies all competing with each other and needing multiple coordinating bodies. Yet that may not be such a bad thing. "Living systems have a tendency to become more complex rather than more simple over time. Life, by its very nature, is resistant to simplification," said the physicist Freeman Dyson recently in a lecture, whether "on the level of single cells or ecological systems or human societies."[22] By this criterion, the enormously complex and historically luxurious German system for the organization of research seems very lively indeed.

NOTES

1. On this class boundary as a sociopolitical "frontier," see J. Sheehan, *German Liberalism in the Nineteenth Century,* Chicago: University of Chicago Press, 1978, p.282.

2. On the impact of the skill level of German craftsmen and managers, see J. A. Limprecht and R. H. Hayes, "Germany's World-class Manufactures," *Harvard Business Review,* (November/December 1982), pp. 137-45; and F. D. Weiss, *The Structure of International Competitiveness in the Federal Republic of Germany,* World Bank Staff Working Papers, No. 571, Washington, D.C.: The World Bank, 1983.

3. There is an extensive literature on the development of the German universities and the growth of the German research enterprise. Particularly germane here is the recent look at the professionalization of scientists provided by R. S. Turner, "The Great Transition and the Social Patterns of German Science," *Minerva,* Vol. 25 (Spring-Summer 1987), pp. 56–76; J. Ben-David's suggestive interpretation in *The Scientist's Role in Society,* Englewood Cliffs, N.J.: Prentice-Hall, 1971, pp. 108-38; and the work on the technicians of the period offered by P. Lundgreen in *Techniker in Preussen waehrend der fruehen Industrialisierung,* Berlin: Colloquium Verlag, 1975, and "Education for the Science-based Industrial State? The Case for Nineteenth-century Germany," *History of Education,* Vol. 13 (1984), pp. 59–67.

4. Werner von Siemens to Reich Minister of the Interior Heinrich von Boetticher, 20 March 1984, in W. Siemens, *Wissenschaftliche und Technische Arbeiten,* Vol. II, Springer: Berlin, 1891, pp. 579-80.

5. *Werner von Siemens, Inventor and Entrepreneur: Recollections,* London: Lund Humphries, 1966, p. 266.

6. A. Beyerchen, "On the Stimulation of Excellence in Wilhelmian Science," *Another Germany: A Reconsideration of the Imperial Era,* edited by J. Dukes and J. Remak, Boulder, CO: Westview Press, 1988, pp. 139-68. A similar view based predominantly on medical research is expressed by T. Lenoir, "A Magic Bullet: Research for Profit and the Growth of Knowledge in Germany Around 1900," *Minerva,* Vol. 26 (Spring 1988), pp. 66–88.

7. See B. Schroeder-Gudehus, "Deutsche Wissenschaft und internationale Zusammenarbeit 1914–1928," (Ph.D. dissertation, University of Geneva, 1966, pp. 33–49); and P. Forman, "Scientific Internationalism and the Weimar Physicists: The Ideology and Its Manipulation in Germany after World War I," *Isis,* Vol. 64 (June 1973), pp. 69–71.

8. Rockefeller Archive Center, Rockefeller Foundation, RG 3, Series 900, F 172, "The Foundation Versus Japan," October 1, 1937, and F 174, "Report of the Special Committee on Program and Policy, Dec 3–4, 1946," p. 56.

9. Some of these matters are discussed in A. Beyerchen, *Scientists Under Hitler: Politics and the Physics Community in the Third Reich,* New Haven and London: Yale University Press, 1977. See also *Naturwissenschaft, Technik und NS-Ideologie,* edited by H. Mehrtens and S. Richter, Frankfurt/Main: Suhrkamp, 1980. On the consequences of the regime's policies for business oriented toward research, see especially P. Hayes, *Industry and Ideology: IG Farben in the Nazi Era,* Cambridge: Cambridge University Press, 1987.

10. A useful survey by a key participant is L. Erhard, *Deutschlands Rueckkehr zum Weltmarkt,* Duesseldorf:ECON-Verlag, 1953. Only West German developments will be covered below, but a pertinent source on East Germany is R. Bentley, *Technological Change in the German Democratic Republic,* Boulder, CO: Westview Press, 1984.

11. On some of the implications and context of the Allied prohibitions, see A. Beyerchen, “German Scientists and Research Institutions in Allied Occupation Policy,” *History of Education Quarterly,* (Fall 1982), pp. 289-99. For the most up-to-date analysis of FIAT and Paperclip, see J. Gimbel, *Science, Technology and Reparations: Exploitation and Plunder in Postwar Germany,* Stanford, CA: Stanford University Press, (1990). On the postwar treatment of I. G. Farben, see R. Stokes, *Divide and Prosper: The Heirs of I. G. Farben under Allied Authority, 1945–1951,* Berkeley, CA: University of California Press, 1988.

12. See T. Stamm, *Zwischen Staat und Selbstverwaltung: Die deutsche Forschung in Wiederaufbau 1945–1965,* Cologne: Verlag Wissenschaft und Politik, 1981; and W. Krieger, “Zur Geschichte von Technologiepolitik und Forschungsfoerderung in der Bundersrepublik Deutschland: Eine Problemskizze,” *Vierteljahrshefte fuer Zeitgeschichte 35, Heft 2* (April 1987), pp. 247-71. Also of interest is the paper delivered by David Cassidy at the History of Science Society meeting in Cincinnati, December 1988, “Overcoming the Past: The Search for a Science Policy in Postwar West Germany,” (manuscript kindly made available by its author).

13. L. Erhard, *Prosperity through Competition,* New York: Praeger, 1958, pp. 1–3.

14. On these points, see R. G. Stokes, “Technology and the West German *Wirtschaftswunder,” Technology and Culture,* (in press).

15. Max Planck Institute for Human Development and Education, *Das Bildungswesen in der Bundesrepublik Deutschland,* Reinbeck bei Hamburg: Rowohlt, 1979, translated as *Between Elite and Mass Education,* Albany, NY: State University of New York Press, 1983.

16. Bundesminister fuer Forschung und Technologie, *Bundesbericht Forschung VI,* Bonn: Bundesministerium fuer Forschung und Technologie, 1979, p. 13.

17. See J. Allesch, “Innovation Centres and Science Parks in the Federal Republic of Germany,” *Science Parks and Innovation Centres: Their Economic and Social Impact,* edited by J. M. Gibb, Amsterdam: Elsevier, 1985, pp. 58–68.

18. A. Minc, *La Grande Illusion,* Paris: B. Grasset, 1989. See also B. Nussbaum, *The World After Oil,* New York, Simon and Schuster, 1983, pp. 77–103.

19. See, for example, Heinz-Otto Peitgen and S. Richter, *The Beauty of Fractals,* New York, etc: Springer Verlag, 1986; or *Ordnung aus dem Chaos,* edited by Bernd-Olaf Kueppers, Munich: Piper, 1987. On some of the historical implications of nonlinear science, see A. Beyerchen, “Nonlinear Science and the Unfolding of a New Intellectual Vision,” *Rethinking Patterns of Knowledge, Papers in Comparative Studies* (1988–89), Vol. 6, edited by R. Bjornson and M. Waldman, pp. 25–49.

20. A provocative discussion of the German dimensions of ecology (and some of its implications in the Third Reich) is provided by A. Bramwell, *Ecology in the 20th Century: A History,* New Haven and London: Yale University Press, 1989. A brief discussion in English of the legacy of discredited eugenics for German genetic research is R. Zell, “History Feeds German Fears on Gene Technology,” *New Scientist* (26 August 1989), pp. 26–28.

21. For an argument that West Germany is not lagging behind in new technologies, but is just incorporating them selectively into its competitive posture, see Gerd Junne, “Competitiveness and the Impact of Change: Applications of ‘High Technologies,'” in *Industry and Politics in West Germany,* edited by P. J. Katzenstein, Ithaca and London, Cornell University Press, 1989, pp. 249-74.

22. F. Dyson, *Origins of Life,* Cambridge etc., Cambridge University Press, 1985, pp. 75–76.

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France

RESEARCH, EDUCATION, AND THE INDUSTRIAL ECONOMY IN MODERN FRANCE

Robert Fox
University of Oxford

Traditionally, the French educational system has been seen as the victim of the two debilitating blights of centralization and what I shall inelegantly call functional fragmentation.[1]

The meaning of centralization is obvious. It is encapsulated in the story of the Minister of Education in Paris who had only to look at his clock to know which passage from Vergil or which theorem of Euclid was being expounded in every school throughout the country.

By functional fragmentation I mean the principle that every institution has a narrowly defined, often exclusive function, a function so precise as to suppress overlap and hence competition between institutions. The consequences, according to Joseph Ben-David and other observers, have been stultifying.[2] Certainly, they have represented the antithesis of the intrinsically competitive systems of Germany or the U.S.A.

The peculiarities of the French system of advanced education are embodied in the great vocational schools, the so-called *grandes écoles,* each of them preparing for a specific career. This has always been a flexible system, since it has allowed a new school to be created whenever a new technical career has emerged. Since the first of the present *grandes écoles,* the Ecole des Ponts et Chaussées, was created in 1747, over 150 new schools have been established in science and engineering alone (most of them in our own century), to say nothing of more than seventy commercial and business schools and about eighty others with different vocational specialities.[3] The quality, in such a large sector of education, is necessarily variable, but the most prestigious of the schools, such as the Ponts et Chaussées, the Ecole des Mines, and, most notably, the Ecole Polytechnique, enjoy an incomparable status in the eyes of candidates and their parents.

Research, too, has traditionally been seen as the function of specialized institutions, far fewer in number than the *grandes écoles,* but including some of the glories of French intellectual life, such as the sixteenth-century Collège de France (with its array of chairs across the spectrum of the sciences, the humanities, and the social sciences), the Paris Observatory (the creation of Louis XIV), and the Muséum National d'Histoire Naturelle (the post-revolutionary descendant of the Jardin du Roi).

Finally, the most unwieldy element of all, is the university system. This was a single national administration from the time of its creation by Napoleon in 1808 until its division into fifteen separate universities in 1896, and over its history its functions have varied. Initially, at least, the nineteenth-century university was conceived as a means of providing examiners for the national examinations (for the *baccalauréat,* the *licence,* the doctorate, and the competitive *agrégation),* though it was also seen as a vehicle for lectures (to both students and the general public) and, secondarily, as an institution for research, complementing in a rather unstructured way the contribution of the designated research institutions.

This first-order impression of the French system underlines the characteristics of orderliness and functional tidiness. Yet, for my present purpose, it is important to note that research, in this structure, has a distinctly uncertain place. It has always been recognized that professors in any institution, even in the *grandes écoles* with their emphasis on vocational training, could perform research, and the reputation of the Ecole Polytechnique in its early golden age rested in large measure on the intellectual distinction of teachers of the calibre of Monge, Ampére, Gay-Lussac, Petit, and Thenard. But it was only when France was wafted by the international currents of reform in the later nineteenth century that research came to be seen as one of the primary duties of the academic profession, in particular of teachers in the universities.

This rather late acceptance of the centrality of research could hardly have been otherwise, since an awareness of the new German conceptions of the intellectual role of the professoriate was forced on France (as on no other country) only after the defeat of 1870. Convinced that the German professoriate was responsible for the *débâcle* of Sedan, reformers in France urged that their country should go down the German road of universities that were independent and multi-functional, possessing a commitment to innovation as well as to teaching and examining.[4]

As an abundant secondary literature has shown, the French educational system responded with alacrity, trying to graft a German model onto the centralized bureaucratic structure I have described.[5] Accordingly, reform began strongly. Through the 1880s and 1890s, universities and individual faculties were encouraged to raise funds locally and to break out of their ivory towers. The consequences, in the sciences and technology, were a host of new courses and specialized institutes devoted to such subjects as electrical technology (at Nancy, Lille, Grenoble, and Toulouse), industrial chemistry (at Lyon and Lille), and wine-making (at Dijon). Vocational teaching was fostered, along with applied research, and the institutions prospered through donations from municipal and departmental councils, chambers of commerce, and industrialists. Before the First World War, this non-ministerial support had grown so substantial that the old frugality of the university sector seemed a thing of the past, and the constraints of centralized control were greatly reduced.

At last, university science had a role, but I would argue that, if anything, the response to immediate economic demand between the 1880s and 1914 was too keen. To please local sponsors, the buildings that the new patronage bought had to be of an appropriate grandeur with little thought for their versatility, for example. Moreover, the teaching had to be of a precise, immediately applicable nature, with consequences that encouraged a rather unimaginative approach to instruction and helped to reinforce a conception of research oriented heavily to the testing and routine measurement which industrialists demanded.

So it was that the French scientific community came to the First World War in a state of relative detachment from anything resembling a national plan and with governmental attitudes that bordered on benign indifference, as far as the research function was concerned. The favoured "stars" were supported well enough; Marie Curie's Institut du Radium, founded in 1909, was a showpiece. But a major electrical congress in London in 1908 laid ruthlessly bare the weaknesses at more modest levels. In an international plan to promote the standardization of units and standards, Germany could offer her Physikalisch-Technische Reichsanstalt, the U.S.A. had the National Bureau of Standards, and Britain proffered the National Physical Laboratory. France, predictably, had only a handful of individuals working in the modestly equipped and privately funded Laboratoire Central d'Electricité and some other small testing laboratories; and it was only an intense last-minute protest which ensured that she was represented at all in the international network of national laboratories.[6]

All too soon afterwards, the consequences were to be seen once again. From 1914, individual scientists made an impressive response to the challenge of warfare but they did so in conditions that rendered a well-financed, coordinated effort impossible. As L. F. Haber has argued, French scientific achievements in response to Germany's use of gas, though considerable, make both sides of this point plainly enough.[7]

The tendency for the activity of science to be seen overwhelmingly as a matter of teaching and the passing on of a cultural tradition, or of applied contract research, rather than a valued quest for novelty, persisted after the First World War. Now, local patrons and national governments alike appeared unable or unwilling to meet the mounting cost of research, and French laboratories entered a period of neglect that aroused concern even in non-scientific circles. Quickly, however, scruffiness came to be seen as part and parcel of the scientific enterprise. Between the wars, the quintessential *savant,* in the public's and most governments' eyes, was Edouard Branly, the contemporary and rival of Marconi, and the inventor of the coherer (an essential component in early wireless communication). By the time Branly acquired a serious working laboratory in 1932, he was 88. And even in his new premises, which came to him as a private donation (stimulated as much by his association with the cause of Catholic higher education as by his scientific reputation), he continued to work, as he always had done, with just one assistant.[8] It seems that the desirability of establishing a team or a school was never seriously countenanced. Branly would complain about the conditions in which he worked, but he did so with a limited view to improving facilities for his own research. Despite the availability of a few alternative role models, most notably at the handsomely endowed Institut Pasteur, where team research was encouraged, the man of science was cast firmly as a solitary searcher for truth who throve on hardship.

Any explanation of these dominant attitudes to scientific research and of ministerial indifference to the conditions that prevailed in French laboratories between 1918 and 1939 must take account of elusive cultural prejudices. These prejudices fostered individualism and made it appear normal, even desirable, that research should be conducted in a large number of small laboratories in which dilapidation was a price willingly paid for independence and a strong hold over such matters as the choice of problems and the all-important matter of the succession when a Director died or retired.

But an even more potent influence was the industrial economy of France, which in giving little reward to the independent introduction of new processes and products had taken a path very different from those of Germany or the U.S.A. The history of the new science-based industries of the later nineteenth century—artificial dyestuffs and electrical equipment, in particular—displays an uncannily regular pattern, with France getting off to a good start when the sector was small and the technology crude, but then flagging and failing to invest in innovation.[9] In retrospect, the failure to go the way of the Bayer Company or General Electric—the way of intensive research and patenting—may appear a mark of culpable miscalculation. However, seen from within contemporary French industry, it was by no means obvious that a heavy expenditure on laboratories and a strategy based on independent innovation could ever be justified. Indeed, even in Germany and the U.S.A., the large company laboratory was a phenomenon of the period of consolidation, after the large research-oriented companies had accumulated capital far in excess of the equivalent sums for France. The case of Bayer is telling and typical. For it was only in the 1890s, nearly forty years after the creation of the first artificial dyestuff by W. H. Perkin in 1856, that Bayer opened its first substantial company laboratory.[10] By then, but only then, many years of profits had provided the essential elbow-room that made it possible to embark on a totally unprecedented course of long-term planning for new products, such as synthetic indigo (the fruit of fifteen years of intense effort in the company laboratory). In this, there are obvious parallels with the strategy that led to the protracted development of the tungsten filament lamp in the laboratory of the General Electric Company.[11]

It might have been expected that as such firms as Bayer, General Electric, BASF, Hoechst, and AEG grew ever more rapidly (from the late 1890s), French companies would be moved to emulation. The Compagnie Générale d'Electricité was one company that did respond, lacing the publicity that accompanied its launch in 1898 with a nationalistic lament about the invasion of electrical manufacturing in France by foreign technology.[12] But very rapidly the resolve waned, and the goal of developing a range of independent products was abandoned. Within a few years, the CGE had reverted to a traditional policy of technological dependence, in particular on patents leased from the Swiss firms of Brown-Boveri and Ahlstom.

The indifference of French companies towards “in-house” research, apart from an essential degree of routine testing and quality control, was profound and lasting.[13] In the short term, perhaps, this need not have been a source of weakness. The case of the Italian electrical industry, which enjoyed great economic success while pursuing just such a policy between the 1890s and 1914, makes the point plainly enough.[14] But, for my present argument, the importance of the absence of any sustained quest for innovation is that it detached research from the main stream of economic activity and helped to reinforce the traditional view of science as a personal pursuit of truth not significantly different from scholarship in the humanities. It also suppressed the industrial demand for employees trained in applied research, with clear consequences for the kind of training that educational institutions felt it proper to provide.

It was on the eve of the Second World War that these attitudes began to change. In the 1930s, in the brief period of the left-wing Popular Front, under the influence of Paul Langevin and Jean Perrin, there had been some attempt to make scientific research a major responsibility of government. This culminated, in 1939, in the founding of the Centre National de la Recherche Scientifique (CNRS), as a national body that would break aggressively with the past, not only by encouraging research but also, and more specifically, by fostering cooperation and breaking down the barriers and intellectual fiefdoms that were integral to the old system of patronage.[15]

The founding of the CNRS can be seen as the first salvo in a continuing struggle by a succession of pressure-groups and governments to detach scientific research from its traditional institutional setting. (See Table 1.) After the war, the momentum was maintained, with the confirmation of the CNRS and the reaffirmation of a deliberate interventionism through the creation of the Commissariat à l'Energie Atomique (CEA), which (in a manner

TABLE 1

MAJOR FRENCH NATIONAL RESEARCH ORGANIZATIONS

Title	Date of foundation
Centre National de la Recherche Scientifique (CNRS)	1939
Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM)	1943
Centre National d'Études des Télécommunications (CNET)	1944
Commissariatà l'Énergie Atomique (CEA)	1945
Institut National de la Recherche Agronomique (INRA)	1946
Centre National d'Études Spatiales (CNES)	1961
Institut National de la Santé et de la Recherche Médicale (INSERM)	1964
Institut National de Recherche d' Informatique et d' Automatique (INRIA)	1967
Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)	1967

entirely characteristic of the new thrust of policy) combined national status with an immense degree of autonomy encapsulated in the personality of its Director, Frédéric Joliot-Curie, a hero (at least of the Left) who soared above established interests.[16]

For a while, it seemed that the CNRS and the CEA were to be the harbingers of unprecedented change in the patronage of French science. But if Joliot-Curie's communist sympathies were acceptable enough in the immediate postwar reaction against what the Left liked to portray as the dead hand of the universities, they soon underlined the dangers inherent in the politicization of science. As the Cold War intensified, there were inevitable questions of trust. In 1950, Joliot-Curie was dismissed, and gradually the traditional élite, with its strong representation of former *polytechniciens* and predominantly conservative political sympathies, reasserted itself, at least in the higher reaches of the CEA.

It was with the beginning of the Gaullist era, strengthened by stability and a new sense of national pride, that the false dawn of the late 1940s became an irreversible reality. Immediately on coming to power in 1958, De Gaulle declared scientific research to be a key to the national independence and economic prosperity of France, and suddenly what had been seen as a relatively minor element in governmental planning assumed the status of a priority. Hitherto the series of three-to six-year plans for postwar reconstruction, begun under Jean Monnet in 1946, had done little for research, beyond articulating the sense that France had fallen seriously behind as a scientific nation. Under the Fifth Republic, research became the motor of social and economic planning, most obviously from the time of the Fourth Plan, covering the years 1961–1965.[17]

With centralization rehabilitated and *dirigisme* back at the heart of policy, a major restructuring of the committee network took place. A new Délégation Générale à la Recherche Scientifique et Technique (DGRST) was established to serve as a joint secretariat for two national advisory committees—the Comité Interministériel de la Recherche Scientifique et Technique (CIMRST) and the Comité Consultatif de la Recherche Scientifique et Technique (CCRST, or the "Comité des Sages" as it came to be called)—whose function was to establish and implement a plan for research that would transcend the traditional divisions between ministries. Significantly and quite crucially, the DGRST was to be answerable directly to the Prime Minister.

The result of this new structure and of the dedication and freshness of the generation of younger scientists, engineers, and industrialists who rose to prominence within it was a degree of coherence in planning that has characterized France's effort in research ever since. The first head (Délégué-général) of the DGRST, Pierre Piganiol, set the tone with a continuing programme of evaluation and designation of areas of priority which had prominent repercussions in all the subsequent national economic plans.[18] These repercussions were to be seen even when enthusiasm for research waned slightly, as it did at times during the centre-right Presidencies of Georges Pompidou and Valéry Giscard d'Estaing (despite the fact that the promotion of science and technology was now firmly equated with emulation of the U.S.A., rather than of the Soviet Union, which had been the main model of reformers in the immediate postwar period).

Predictably, there were scientists who protested. But their argument that basic research cannot be planned paled as those who were willing to follow the designated research priorities found themselves spoiled. Time and again, the forced channelling of funds into priority areas allowed France to leap ahead, in telecommunications technology, for example, and in her vigorous nuclear power programme and military technology. Usually the mechanism would be a specialized governmental agency, such as the CEA, the Centre National d'Etudes des Télécommunications (CNET), or the Centre National d'Etudes Spatiales (CES), but the national plans in which the priorities have been spelled out have always fostered ways of diverting a share of the budget for research towards academic institutions and private industry. Both Thomson and Aérospatiale have been major beneficiaries of this policy, which has ensured that the dependence of research and development on state funding has been proportionately very much higher in France than in, say, the U.S.A. The figures of 55 percent for the proportion of expenditure on scientific and technological research coming from the state in France and less than 30 percent for the U.S.A. in recent years give a measure of the contrast.

It is tempting to advance this structure of technologically oriented and carefully guided research as something approaching an ideal. Certainly, the results since 1958 have been impressive, as anyone who has witnessed the spectacular modernization of France must agree. The losers, unquestionably, have been the university scientists in the classic mould who have pined for the days of completely open-ended research. The gainers have been the far greater number of scientists who have adjusted to the new style of patronage, salvaging at least a measure of control from a process of public consultation between governments and the scientific community that has had some remarkable manifestations. One, predating the Gaullist era, was a colloquium of 150 scientists, industrialists, and political figures, held at Caen in an atmosphere of crisis in 1956.[19] Another was the consultation of 1982, when 25,000 scientists, technologists, and engineers from both the state and the private sectors participated in a series of regional meetings and a final national colloquium on educational and research policy stimulated by the election of the new socialist President, Francois Mitterand.[20]

The effectiveness of consultation on this scale is, of course, open to question. It has also been suggested that the period embraced by the successive National Plans is too long to allow for the short-term changes of direction that might be coped with rather better in a company involved in a constant review of its policies and priorities. A five-year plan may indeed be hard to reconcile with flexibility of this kind. But, looking back over the history of technical education and research in the last hundred years or so, I am convinced that closeness to the market can be a handicap. It risks a diversion of attention from what I see, not least in the context of the problems of present-day Britain, as a pressing need for more attention to the medium and the long term.

In fact, my own reaction to the rhythm of the French process of planning is that the five-year periods of the plans may not be long enough. They allow new specialities to be abandoned before they are established, and they scarcely give time for the training of researchers, who come predominantly through the slower and more conservative mechanisms of the university system.

In conclusion, it seems unsurprising that the dynamic reforms of the last thirty years have yielded both successes and failures. It could scarcely be otherwise when planning in research is being attempted in an academic structure that is still, at bottom, wedded to a profile of teaching not necessarily supportive of new departures. Yet through its designation (at ministerial level) as a priority area and the focus of a major “action thématique programmée” (ATP), molecular biology is just one discipline that has been fostered to a degree that would have been inconceivable in the context of a single university. For the failures, we have to look to fields that have not enjoyed priority status and to the recurring patchiness of France's performance in industrial research in these areas which has been a recurring source of concern to the ministers responsible since the early 1980s. Especially notable, and disturbing, is the sharp contrast between the relatively high investment in research and development (much of it directly or indirectly helped by governmental funding) in aviation, electronics, or nuclear power, and the modest financing of R and D in the automobile industry, metallurgy, food and agriculture, and many branches of chemistry, where encouragement by governments has traditionally been slight.[21] It remains to be seen whether tax and other incentives introduced since 1983 to encourage expenditure on research by smaller firms will eventually lessen this disparity.

It will be clear from all this that, despite the failures, I take a somewhat more favourable view of the French system than Luc Rouban, in his recent book, *L'Etat et la science. La politique publique de la science et de la technologie.*[22] Where Rouban identifies a gathering "crisis" in the 1980s, with governmental policy unable to cope coherently with the multiple and often conflicting demands of society, I tend to see a constructive ministerial response with its roots (though not its only inspiration) in the heady early days of socialist dominance that began with the election of Francois Mitterand as President of the Republic and the creation of the first government of Pierre Mauroy, both in May 1981.[23]

The Mauroy administration took one of the most significant steps in favour of research that we have seen in the history of modern France. The creation of a Ministry of Research and Industry in that administration was conceived both as a declaration of the importance that was attached to research in all its forms and of a determination, in this privileged area, to extend the vision of the general five-year plans (whose efficacity, in any case, had been called in question since the later 1960s).[24] From the start, the ground was laid overtly for expansion, and barely a year later, in July 1982, the expansion began to take shape in the governmental programme enshrined in the LOP (*Loi d'orientation et de programmation de la recherche et du développement technologique de la France*), which can be seen as a realization of the process of consultation on research conducted earlier in the year.[25]

The vision was a captivating one. It was intended that the proportion of the GNP devoted to research and technological development would increase from 1.8 percent to 2.5 percent between 1981 and 1985, and that there would be an increase of 4.5 percent per annum in the number of scientists and engineers employed in the main national research organizations, accompanied by a comparable growth of posts in higher education. There was also to be a determined push in the direction of greater cooperation between governmental and academic laboratories and private industry; here, a reinvigorated Agence Nationale pour la Valorisation de la Recherche (ANVAR) was to be given a central role in facilitating the economic exploitation of new scientific and technological ideas.[26] However, the budget for R and D grew to only 2.1 percent of the GNP by 1985, and there were signs of a slight weakening of resolve in the mid-1980's, even before the Left lost power in the legislative elections of 1986. It is significant that as head of the Ministry of Research and Technology (1981–1982) and of its successor, the Ministry of Research and Industry (1982–1983), Jean-Pierre Chevénement had the select title of a Minister of State. Thereafter, in the third of Pierre Mauroy's governments (1983–1984) and the government of Laurent Fabius (1984–1986) that status was lost. The Ministries of Industry and Research (1983–1984), headed by Fabius, and of Research and Technology (1984–1986), under the influential and energetic leadership of the scientist and writer Hubert Curien, remained important but no longer laid plans with the same confidence that had been characteristic of the early 1980s.[27]

One source of anxiety between 1983 and 1986 was the current of criticism emanating from the political opposition, notably from the right-wing deputy Alain Devaquet. The main charges concerned the cost of the government's patronage of research and the long-term commitment represented by proposals, contained in the LOP, for the formalization of the status of employees in research as *fonctionnaires* with the associated rights and privileges. When the right-wing government of Jacques Chirac was formed, after the elections of March 1986, those anxieties briefly exerted some influence on policy. But it was Devaquet, with the significantly modest rank of a "Ministre délégué" responsible for research and higher education, who now responded to the menacing noises that were being made against the CNRS, the Institut National de la Santé et de la Recherche Médicale (INSERM), and other research organizations. As a result, despite some initial cuts in funding (particularly severe in the budget of ANVAR), the state's support for research was soon restored very nearly to its former levels. Even more importantly, the essential structure of research laboratories and institutions remained intact, though the bond between research, technology, and industry was distinctly loosened in favour of the more traditional association between research and higher education (both Devaquet and his successor in the Chirac administration, Jacques Valade, being answerable to the Ministry of National Education rather than to the Ministry of Industry, Posts, and Tourism).

For all the anxieties that some researchers voiced during the two years of the Chirac government, the absolute growth in the governmental budget for research and technological development through the 1980s has been consistent and large enough to calm most critics, even if it has not attained anything like the annual increase of 17.8 percent (for civil purposes) that was set in 1982 as a target for the period 1982–1985.[28] The CNRS, with its 1300 laboratories and research groups, 17000 researchers and engineers, 8500 technicians and administrators, and annual budget of 10 000 million francs, has just celebrated its fiftieth anniversary in a spirit of great optimism. And even in the universities and the *grandes écoles,* which in the 1960s still tended to be set apart from the relatively prosperous world of the organizations for research, the new wave of planning has won support. One irresistible attraction has been the implantation of CNRS groups in university laboratories, a procedure that has accelerated the diversion of significant research funding into higher education and helped further to erode the traditional French divide between research and teaching. It is a mark of the success of this diversification that *polytechniciens* too have been touched by the new spirit: in recent years nearly fifty of the Ecole Polytechnique's annual graduating class of about 300 have gone on to careers in research, often (at least in their early years as researchers) within Polytechnique itself.

Plainly, a definitive assessment of these latest new departures is impossible. We just do not know what will happen to a favoured "secteur de pointe" that loses its status and privileged support; and it cannot be pretended that the old rivalries between the universities and the CNRS, or between the advocates of open-ended research and those with more immediate expectations of an economic return, have completely disappeared. But the benefits of thirty years of a coordinated national policy for research are unmissable and, at least to British eyes, enviable. Most striking of all is the fact that the pace of the development of research seems, if anything, to be quickening, as successive governments continue to foster areas of special priority and as, in the population at large, reticence towards the spirit of industry and enterprise, so characteristic of France before the 1950s, or even the 1980s, passes into the recesses of the national memory.

NOTES

1. I base this statement on the standard literature of which Robert Gilpin, *France in the Age of the Scientific State* Princeton: Princeton University Press, 1968, is typical. For an alternative view that stresses the flexibility and underestimated degree of decentralization in the system, see R. Fox and G. Weisz, “The Institutional Basis of French Science in the Nineteenth Century,” *The Organization of Science and Technology in France, 1808–1914,* edited by R. Fox and G. Weisz, Cambridge: Cambridge University Press; Paris: Editions de la Maison des Sciences de I'Homme, 1980, pp. 1–28.

2. See, in particular, J. Ben-David, *The Scientist's Role in Society, A Comparative Study,* Englewood Cliffs, N.J.: Prentice Hall, 1971, pp. 88–107.

3. For convenient listings of these schools, see the guides for potential candidates for admission, such as the annual *Devenez ingeniéur. Le guide des formations et des carrières,* from which much of my statistical information is drawn.

4. For some classic contemporary statements of the view that France had been defeated by “German science,” see the views of Henri Sainte-Claire Deville, Armand Quatrefages de Bréau, and others in *Comptes rendus hebdomadaires de l'Académie des Sciences,* Vol. 72 (1871), pp. 237-9 and 261-9.

5. See, for example, T. Shinn, “The French Science Faculty System 1808–1914: Institutional Change and Research Potential”, *Historical Studies in the Physical Sciences,* Vol. 10, 1979, pp. 369-82; G. Weisz, *The Emergence of Modern Universities in France, 1863–1914,* Princeton, N.J., 1983; R. Fox, “Science, the University, and the State in Nineteenth-century France,” *Professions and the French State, 1700–1900,* edited by G. L. Geison, Philadelphia, 1984, pp. 66–145; H. W. Paul, *from Knowledge to Power, The Rise of the Science Empire in France, 1860–1939,* Cambridge, 1985; M. J. Nye, *Science in the Provinces. Scientific Communities and Provincial Leadership in France, 1860–1930,* Berkeley, Los Angeles, and London, 1986.

6. H. Le Chatelier et. al., “Rapport sur les laboratories nationaux de recherches scientifiques,” *Comptes rendus… de l'Academie des Sciences,* Vol. 163 (1916), pp. 581-8 (583).

7. L. F. Haber, *The Poisonous Cloud. Chemical Warfare in the First World War,* Oxford, 1986, especially chapter 6.

8. Pierre Jacques, *La vie laborieuse d'Edouard Branly,* Paris, 1942.

9. For my own views on this pattern, see Robert Fox, “Contingency or Mentality? Technical Innovation in France in the Age of Science-based Industry,” *Technological Education-Technological Style,* edited by Melvin Kranzberg, San Francisco, 1986, pp. 59–68.

10. G. Meyer-Thurow, “The Industrialization of Invention: A Case Study from the German Chemical Industry”, *Isis,* Vol. 73 (1982), pp. 363-81.

11. The need for a strong existing economic base before a significant programme of fundamental research can be embarked upon is also bought out in Leonard S. Reich's study of research at General Electric: *The Making of American Industrial Research. Science and Business at GE and Bell, 1876–1926,* Cambridge, 1985.

12. A. Broder, “La multinationalisation de I'industrie électrique francaise, 1880–1931: causes et pratiques d'une dépendance”, *Annales ESC,* 39e année (1984), pp. 1020-43 (1020). The passage cited on p.1020 illustrates very clearly my point about the nationalistic tone of the leaders of the CGE at its foundation.

13. The sluggishness of the growth of "in-house" industrial research in France is brought out well in Terry Shinn's, "The Genesis of French Industrial Research 1880–1940," *Social Science Information,* Vol. 19 (1980), pp. 607-40.

14. A. Guagnini, "The Formation of Italian Electrical Engineers: the Teaching Laboratories of the Politecnici of Turin and Milan, 1887–1914," in *Un siècle d'électricité dans le monde, 1880–1980,* edited by Fabienne Cardot, Paris, 1987, pp. 283-99.

15. Frédéric Blancpain, "La création du CNRS: histoire d'une décision 1901–1939," *Bulletin de I'Institut International de I'Administration Publique,* Vol. 32, 1974, pp. 93–143.

16. On the early history of the CEA and of Joliot-Curie's role in it, see B. Goldschmidt, *The Atomic Adventure. Its Political and Technical Aspects,* trans. by P. Beer, Oxford, 1964, pp. 59–65; L. Scheinman, *Atomic Energy Policy in France under the Fourth Republic,* Princeton, N.J., 1965, chapters 2 and 3; and P. Biquard, *Frédéric Joliot-Curie. The Man and His Theories,* trans. by G. Strachan, London, 1965, chapter 5.

17. For an autobiographical account of a major figure who lived through this transformation, in his capacity as Commissaire du Plan between 1959 and 1966, see Pierre Massé's *Aléas et progrès. Entre Candide et Cassandre,* Paris, 1984, especially chapter 3.

18. For an impression of Pierre Piganiol's resolute but always realistic view of the need for planning in science and technology, see his reflective book *Maitriser le progrès,* Paris, 1968.

19. Papers written for this Colloque National and the resulting proposals are reproduced in a special issue of *Les cahiers de la République,* 2e année, no. 5 (January–February 1957).

20. *Actes du colloque national recherche et technologie,* Paris, 1982. The new law that resulted from this consultation is referred to in note 24, below.

21. On the historical persistence of this contrast, see H. W. Paul and T. Shinn, "The Structure and State of Science in France," *Contemporary French Civilization,* Vol. 6 (1981-2), pp. 153-93 (176-81).

22. See Luc Rouban, *L'Etat et la science. La politique publique de la science et de la technologie,* Paris: Centre National de la Recherche Scientific, 1988.

23. For a generally sympathetic review of science policy under the successive socialist administrations of the early and mid 1980s, see P. Papon, "Science and Technology Policy in France, 1981–1986," *Minerva,* Vol. 26 (1988), pp. 493–511. Although it is an important part of my argument that the tide had been running strongly in favour of research since the accession of President De Gaulle in 1958, the signs of anxiety about the state of research in France in the later years of the Presidency of Valéry Giscard d'Estaing are unmistakable. See, most notably, the review of French provision for all sectors of research presented to the President of the Republic in September 1980 by a committee under the chairmanship of Monsieur Jacques Friedel: *Construire I'avenir. Livre blanc sur la recherche présenté à Monsieur le Président de la République,* Paris, 1980. The "Prologue" to the report speaks of the profound "malaise" of the research community and itemizes complaints ranging from the excessive bureaucratization of research to what was seen as a weakening of governmental support through the 1970s.

24. The doubts concerning the appropriateness of the plans, from the time of the Fifth Plan (1966–70), are reflected in the contributions to a conference organized by the Institut d'Histoire du Temps Présent in 1985. See H. Rousso (ed.), *La planification en crises (1965–1985),* Paris, 1987; and cf. the more favourable view of the first four plans conveyed in H. Rousso (ed.), *De Monnet à Massé,* Paris, 1986.

25. The text of this law was published, with associated documentation, in the *Journal officiel de la République Francaise,* 114e année, no. 163 (15–16 July 1982), pp. 2270-80.

26. ANVAR had been created in 1967 to facilitate the development of innovations emerging from both industrial and governmental laboratories. In the 1980s, it has had a particularly important role in support of the research efforts of smaller industrial companies.

27. The appointment of Hubert Curien reflects the relative ease with which the French system of administration admits figures with particular expertise from outside the political world. At the time of his appointment, Curien was President of the Centre d'Etudes Spatiales, one of the most important of the national agencies for research.

28. *Journal officiel* (cited in note 24, above), pp. 2270 and 2274. The budget for this purpose in 1982 stood at 25400m francs.

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APPENDIX

SYMPOSIUM AGENDA

The University Research Enterprise Within the Industrialized Nations: A Comparative Perspective
Lecture Room, National Academy of Sciences
2101 Constitution Avenue, N. W., Washington, D.C.
March 23, 1989

9:00 am	WELCOMING REMARKS	James D. Ebert, Chairman Government-University-Industry Research Roundtable
9:15 am	MORNING SESSION	
	Chairperson	Nathan Reingold, Smithsonian Institution
	United States	Roger L. Geiger, The Pennsylvania State University
	Japan	James R. Bartholomew The Ohio State University
	Soviet Union	Mark B. Adams, University of Pennsylvania
10:45 am	OPEN DISCUSSION	Erich Bloch, Director National Science Foundation
		T. Alexander Pond, Rutgers University
1.00 pm	AFTERNOON SESSION	
	Chairperson	Mary Jo Nye, University of Oklahoma
	Great Britain	Sheldon Rothblatt, University of California, Berkeley
	Federal Republic of Germany	Alan D. Beyerchen, The Ohio State University
	France	Robert Fox, University of Oxford
2:30 pm	OPEN DISCUSSION	Erich Bloch, Director National Science Foundation
		T. Alexander Pond, Rutgers University
3:30 pm	CLOSING REMARKS	Erich Bloch, Director National Science Foundation

SYMPOSIUM PANELISTS

Mark B. Adams Associate Professor of History and the Sociology of Science University of Pennsylvania Philadelphia, PA 19104

James R. Bartholomew Associate Professor of Japanese History Department of History The Ohio State University Columbus, Ohio 43210-1311

Alan D. Beyerchen Professor Department of History The Ohio State University Columbus, Ohio 43210-1367

Erich Bloch Director National Science Foundation 1800 G Street, NW Washington, DC 20550

James D. Ebert Director Chesapeake Bay Institute The Johns Hopkins University The Rotunda-Suite 340 711 West 40th Street Baltimore, MD 21211

Robert Fox Professor of the History of Science Modern History Faculty University of Oxford Broad Street Oxford OX1 3BD England

Roger L. Geiger Associate Professor of Higher Education Higher Education Program The Pennsylvania State University University Park, PA 16082

Mary Jo Nye Professor, History of Science Department of History University of Oklahoma Norman, OK 73019

T. Alexander Pond Executive Vice President Rutgers-The State University of New Jersey New Brunswick, NJ 08903

Nathan Reingold Senior Historian Joseph Henry Papers American History Museum, Rm 4027 Smithsonian Institution Washington DC 20560

Sheldon Rothblatt Professor Department of History University of California Berkeley, CA 94720-0001

SYMPOSIUM PARTICIPANTS

Mark B. Adams Associate Professor of History and Sociology of Science University of Pennsylvania

Robert Althauser Associate Program Director Sociology Program, Division of Social & Economic Science National Science Foundation

Cezary Ambroziak Embassy of Poland

John P. Andelin, Asso. Dir. Office of Tech. Assessment

Toby Appel Historian, Biological, Behavioral and Social Sciences National Science Foundation

Robert Atwell, President American Council on Education **Michel Aubry** Scientific Counselor Embassy of France

Harvey Averch Senior Staff Associate Office of the Director National Science Foundation

Thomas J. Baerwald Program Director, Geography & Regional Science Program National Science Foundation

James R. Bartholomew Assoc. Prof. of Japanese History Department of History The Ohio State University

Tim Beardsley

Scientific American

Charles M. Benbrook, Exec. Dir. Board on Agriculture National Research Council

Alan Duane Beyerchen, Professor Department of History The Ohio State University

James H. Blackman Deputy Division Director Div. of Social & Economic Sci. National Science Foundation

Erich Bloch, Director National Science Foundation

Anthony Boccanfuso Dept. of Govt. Relations and Science Policy American Chemical Society

David Bodde, Executive Director, Comm. on Eng. & Technical Syst. National Research Council

Charles N. Brownstein Directorate for Computer & Information Science & Engin. National Science Foundation

Stephen Brush Committee on the History & Philosophy of Science

John Burris Executive Director, CLS National Research Council

John P. Campbell Senior Program Officer Govt.-University-Industry Research Roundtable National Academy of Sciences

Charles O. Campbell, Dir. Legislative & Govt. Affairs National Society of Professional Engineers

Robert Caplan Executive Director, CBASSE National Research Council

Marta Cehelsky Senior Policy Analyst National Science Foundation

Mary Clutter Acting Assistant Director Division Director, Cellular Bioscience National Science Foundation

Colleen Cordes

Chronicle of Higher Education

Robert W. Corell Directorate for Geosciences National Science Foundation

Dale Corson President Emeritus Cornell University

John Crowley Vice President Association of American Universities

Hemalata Dandekar Associate V.P. for Research University of Michigan

Thomas B. Deen, Exec. Dir. Transportation Research Board National Research Council

Vinnie DelGuidice United Press International

Denis Dewez Scientific Counselor Embassy of Belgium

James D. Ebert Director Chesapeake Bay Institute

Alan Fechter Executive Director, OSEP National Research Council

Robert Fox Professor, History of Science Modern History Faculty University of Oxford

Roger L. Geiger Associate Professor of Higher Education Higher Education Program The Pennsylvania State University

Richard J. Green, Asst. Dir. Directorate for Scientific, Technological & International Affairs National Science Foundation

Dan Greenberg

Science and Government Report

Carl W. Hall Acting Assistant Director Directorate for Engineering

Martha Harris, Director Office of Japanese Affairs Office of International Affairs National Research Council

W. Franklin Harris, Exec. Officer Biological, Behavioral and Social Science Division National Science Foundation

James Fred Hays Senior Science Advisor Office of the Director National Science Foundation

William G. Herrold Institute of Electrical & Electronics Engineers

Allan Hoffman, Exec. Dir. Govt. & External Affairs National Research Council

Constance Holden *Science*

Rachelle D. Hollander Ethics and Values Coordinator National Science Foundation

John Holmfeld Science Consultant Committee on Science, Space, and Technology

John Hurley Director, BOSTID Office of International Affairs National Research Council

John Jennings Committee on Education & Labor U.S. Senate

Robert Kargon Department of History of Science The Johns Hopkins University

Casey Kiernan Senior Program Officer Govt.-University-Industry Research Roundtable National Academy of Sciences

Damien Kulash Executive Director, Strategic Highway Research Program National Research Council

Kamien Kulash, Exec. Dir. Strategic Highway Res. Prog. National Research Council

Stuart Leslie Department of History of Science The Johns Hopkins University

Susan Ruth Levin Arlington, Virginia

Sheldon I. Lippman Project Coordinator NAS Film Committee National Academy of Sciences

Edward Macias Washington University

George Mazuzan Historian National Science Foundation

Roy McCloed National Museum of American History Smithsonian Institution

Larry McCray Director, COSEPUP National Academy of Sciences

Jean McDonald Sr. Policy Analyst National Governors Association

Kim McDonald *Chronicle of Higher Education*

Steve Merrill, Director Office of Govt. Affairs National Research Council

Norman Metzger Deputy Executive Officer National Research Council

Lowell Mininger Group Director, Science & Technology General Accounting Office

Phyllis Moen, Program Director Sociology Program, Division of Social & Economic Science National Science Foundation

Arthur Mollela Chair, Department of History of Science & Technology Natl. Museum of American History Smithsonian Institution

John H. Moore Deputy Director National Science Foundation

David B. Nelson, Exec. Dir. Office of Energy Research U.S. Department of Energy

Sara B. Nerlove Associate Program Director Geography & Reg. Science Program National Science Foundation

Daniel Newlon Program Director, Economics Division of Social & Economic Sciences National Science Foundation

Mary Jo Nye Professor of History of Science University of Oklahoma

Kathryn Olesko Department of History Georgetown University

Grace Ostenso Comm. on Science, Space & Technology U.S. Senate

Ronald J. Overmann, Program Director History & Philosophy of Science National Science Foundation

Joe Palca

Nature

Robert Palmer Comm. on Science, Space & Technology U.S. Senate

Robert Park, Exec. Dir. American Physical Society

Don I. Phillips, Exec. Dir. Govt.-University-Industry Research Roundtable National Academy of Sciences

Lynn Pollnow Program Director, Economics Div. of Social & Econ. Sciences National Science Foundation

T. Alexander Pond Executive Vice President Rutgers University

Thomas Quarles Deputy Division Director Div. of Instr. & Resources National Science Foundation

Victor Rabinowitch Executive Director, Office of International Affairs National Research Council

Thomas Ratchford Associate Executive Officer American Association for the Advancement of Sciences

Kathleen A. Ream Department of Government Relations & Science Policy American Chemical Society

Procter Reid NAE Fellow National Academy of Engineering

Nathan Reingold, Sr. Historian Joseph Henry Papers American History Museum Smithsonian Institution

Richard R. Ries Acting Assistant Director, STIA National Science Foundation

Sheldon Rothblatt Professor, Department of History University of California

Regine Roy Science Counselor Designate Commission of the European Communities

Bertha Rubinstein Washington, D.C.

Anne Scanley Senior Program Officer Govt.-University-Industry Research Roundtable National Academy of Sciences

Carol Scheman Director of Federal Relations for Health & Biomedical Research Association of American Univ.

Glenn Schweitzer Director, Committee on U.S.S.R. and Eastern Europe Office of International Affairs National Research Council

Frank P. Scioli, Program Director Political Science Program Division of Social & Economic Sciences National Science Foundation

Bassam Z. Shakhashiri Assistant Director Directorate for Science & Engineering Education National Science Foundation

Allen M. Shinn, Deputy Director Legislative and Public Affairs National Science Foundation Howard Silver, Exec. Dir. Consortium of Social Science Associations

Sonja B. Sperlich Associate Program Director National Science Foundation

Jeffrey K. Stine Natl. Museum of American History Smithsonian Institution

Marcia Sward Executive Director, MSEB National Research Council

James E. Tavares Board on Agriculture National Research Council

Myron Uman Associate Executive Director CPSMR National Research Council

Thomas van der Voort Subcomm. on HUD-Independent Agencies Senate Committee on Appropriations U.S. Senate

Mitchell Wallerstein Associate Executive Director Office of International Affairs National Research Council

John C. Wooley Div. Director, Instrumentation and Resources National Science Foundation

William Wulf, Asst. Director Directorate for Computer & Information Science & Engin. National Science Foundation

Bernhard Zimburg Scientific Counselor Embassy of Austria