

R&D and the Knowledge-Based Society
Linking the Production, Dissemination, and Application of Research

Proceedings
of the First Sino-US Science Policy Seminar

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The First Sino-US Science Policy Seminar

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Foreword

1999 marked the 20th anniversary of the first bilateral science and technology agreement between the Governments of the United States of America and the People's Republic of China. The cooperative activities pursued since that agreement was signed have been mutually beneficial to both countries, and have resulted in close personal and professional links between their national science and engineering communities.

The US National Science Foundation (NSF) and the National Natural Science Foundation of China (NSFC), both of which are responsible for supporting fundamental research across a broad range of disciplines and for encouraging interdisciplinary pursuits, have played significant roles in facilitating cooperative research between US and Chinese scientists and engineers. Because of the central role they have played in fostering bilateral activities between the research communities in the two countries, these agencies are in a unique position to stimulate exploration of a number of critical policy issues which transcend specific disciplinary interests. Accordingly, a decision was made two years ago to organize jointly a series of policy-related meetings over the next decade dealing with issues with significant implications for the vitality of science and engineering in the increasingly borderless, knowledge-based society that will characterize the new century.

The opening event in this decade-long dialogue was a science policy seminar held in Beijing from October 24–27, 1999, on the general theme: R&D and the Knowledge-Based Society: Linking the Production, Dissemination, and Application of Research. The Beijing seminar, which brought together 12 active participants from the government, industrial and academic research sectors of each country as well as a number of observers, adopted a broad brush approach by exploring several areas of mutual interest in which more focused, intense discussions may be warranted in the future: (1) information and data requirements for policy making; (2) human resources for science and engineering; and (3) the changing character of R&D. Several participants in this seminar have already begun to plan specific follow up meetings.

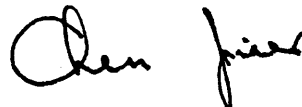
It is our expectation that by making the proceedings of the October 1999 seminar and of subsequent events in the proposed series of Sino-U. S. dialogues available to a broader audience, the circle of individuals and institutions in the two countries who will want to be involved in planning and implementing those events will likewise be broadened. If so, then the science, engineering, and policy communities in our two countries should achieve a deeper understanding and appreciation of differing perspectives and approaches to issues of mutual concern. This should, in turn, improve planning, both nationally and bilaterally, for the effective and balanced development of science and engineering

resources nationally, bilaterally, and globally, as well as the utilization of these resources in the service of important cultural, social and economic goals.

U. S. National Science Foundation

A handwritten signature in black ink, appearing to read "Peter H. Ravn". The signature is fluid and cursive, with a large initial "P" and "H".

National Natural Science Foundation of China

A handwritten signature in black ink, appearing to read "Chen Jian". The signature is cursive and somewhat stylized, with a large initial "C".

Executive Summary

Background. The first Sino-U. S. Joint Science Policy Seminar, co-organized by the National Natural Sciences Foundation of China (NSFC) and the US National Science Foundation (NSF), took place in Beijing, People's Republic of China, from October 24-27, 1999. The seminar was conceived of as the first in a decade-long series of dialogues between representatives from the principal sectors of the science and technology (S&T) enterprise in the two countries. Its theme—*R&D and the Knowledge-Based Society*—was selected to provide opportunities for broad-based discussions about changing demands on, and opportunities for science and technology in the knowledge-based economy or, more broadly, the knowledge-based society. Underlying the selection of this theme was the assumption that a deeper understanding and appreciation of differing perspectives and approaches to associated issues will improve planning—nationally, bilaterally, and regionally—for the effective and balanced development of science and engineering resources and their utilization in the service of cultural, social and economic goals.

The seminar brought together 12 participants from each country with experience in their respective academic, industrial and government sectors. Additionally, several younger Chinese scientists and scholars attended the sessions as observers. Prepared presentations and discussions in plenary sessions and parallel breakout sessions focused on three broad topics: (1) information and data requirements for science policy; (2) human resources for science and engineering; and (3) the Changing Character of R&D.

Information and Data Requirements for Science Policy. The phrase international cooperation, when used in a science policy context, is usually taken to mean R&D cooperation, whether in “big” science projects or the far more common “ordinary” science or engineering projects. However, information exchange is itself an essential type of international scientific collaboration. Information exchange between working scientists and engineers is, of course, necessary to the conception and implementation of specific cooperative R&D programs. At a more fundamental level, information exchange among scientists, policy makers and scholars is an essential prerequisite to more intense, purposeful international research cooperation.

As a case in point, a central objective of the Beijing seminar was to provide an occasion for the latter type of information exchange between and among Chinese and U. S. participants about:

- their current science policy-related interests and concerns, separate as well as shared;
- the principal challenges each side perceives both in advancing their separate national science policy interests and in seeking areas for closer cooperation; and

- their perceived future science policy goals and directions.

Exchange of information of this character can help reduce an important if subtle barrier to international R&D cooperation; namely ignorance on the part on the part of both working scientists and their governments about the capabilities, interests, and motives of potential international partners. In view of the extraordinary opportunities for cooperation that exist now and in the near future, an important aspect of the international science policies of both China and the United States should be to exchange critical information that can help overcome this barrier.

A closely related category of international cooperation in the science policy context involves cooperation in developing and refining internationally comparable statistical indicators to understand better trends in important national and international aspects of the science and technology enterprise. Although this type of cooperation needs to be initiated and pursued by working scientists and scholars, it cannot proceed without the active support, encouragement and -to some extent the participation of -governments.

It is essential to examine, periodically and critically, the question of whether the indicators being developed intersect sufficiently with what policy-makers need to ensure that those policy makers are among the users who find the data useful to have. In the United States, the National Science Foundation's Science and Engineering Indicators Program conducts periodic customer surveys to assure that the data it disseminates remain pertinent to the needs of its users.

A great deal more attention also needs to be paid to measuring the outputs of R&D and the outcomes that reflect the impact of science and technology on society.

International cooperation can be an important means for developing better quantitative measures of outcomes, and to assure the relevance of science and technology indicators to policy makers and science policy scholars.

Human Resources for Science and Engineering. Human resources development, particularly in engineering and the applied sciences, is one of the most important challenges that both China and the United States face. Industrial employers are seeking university graduates who are broader and more interdisciplinary in nature than were their predecessors. Industry needs people with the ability to think logically, adapt quickly, work in teams, communicate their results succinctly, and graduates with a yearning for lifelong learning to keep them ahead of technical obsolescence.

Universities can play roles in economic development, not only by providing well-educated graduates, but also in facilitating technology transfer to industry through programs intended to link the knowledge generation in the universities to business opportunities. Indeed, perhaps the most important of the evolving demands on research universities is to become not just creators of knowledge and knowledgeable individuals, but also to expand their role and methods in the rapid diffusion of

knowledge. This is not necessarily a new role for some universities. But for others it is a dramatic break from their long held views of the role of universities in human resource development and in the innovation system. Government policy can facilitate this, as for example the laws in the United States that give patent and licensing rights for inventions supported by Federal funds to the universities.

Universities can also contribute a great deal to the development of their local regions, California being a prime example in the United States. In China, the Science and Technology University in Hefei is a good example. However, most good universities in China are concentrated in a few cities. How does that influence the national pattern of innovation? What can be done to encourage the coordination and spread of their contribution to the national economy?

Most Chinese participants agreed that reform is urgently required in the Chinese higher education system to reorient education to the output-demand needs of a knowledge-based economy. To accomplish this will require that universities be given greater autonomy in several spheres, including: academic programs and curriculum, administration, and fiscal matters. Rather than having students specialize as soon as they begin college, Chinese universities may benefit from introducing the concept of liberal arts education. Attention will also need to be directed to the education of a managerial group. And of major importance, private universities will need to be encouraged, including universities with international linkages.

The trend toward university-industry cooperation that is beginning to emerge in a few major cities in China has obvious positive implications for the dissemination and application of scientific and technological innovation. But should there be limits to university engagement in business activities, given the potential conflict between industry's desire for short-term research results and the fundamental mission of universities to promote the conduct of long-term basic research?

Changing Character of R&D. Throughout the 1990s, the U. S. Government's R&D expenditures, measured in constant dollars, have remained essentially flat, while industrial expenditures have continued to increase. According to the most recent estimates, U. S. industrial R&D investments in 1999 are expected to be \$ 166 billion, up 12 percent over the estimated \$ 148 billion that was invested in R&D by industry during 1998. This \$ 166 billion represents 68 percent of the \$ 245 billion total R&D effort in the U. S. in 1999. The U. S. Government is expected provide \$ 68 billion for R&D in 1999, or 28 percent of the total, while universities will provide \$ 6 billion of their own funds (2 percent) and non-profit organizations will provide \$ 5 billion (2 percent).

While the prominence of the U. S. Government as a supporter of R&D has continued to decline relative to that of private industry, its importance in encouraging and in formulating and implementing national policies for effective R&D investments has become more important. Government policies now aim to use public-private partnerships as means for meeting societal goals, and to provide a legal framework for these partnerships. Government must also continue to play the vital role as the

principal supporter of basic research in universities and other non-profit institutions.

In China, the central government remains the principal supporter of R&D, and the bulk of R&D funding has traditionally gone to public research institutions and universities in major cities rather than to enterprises. A recent study whose results were reported in the first plenary session of the seminar shows that the overall innovation performance in state-owned enterprises is considerably less than in all other types; e. g. , joint ventures and private companies. Moreover, state-owned enterprises have the smallest proportion of new international products and accounted for only 9.5 percent of total sales. This situation is showing some improvement, as China's policy makers take steps to promote more R&D investments in enterprises. Policy makers have also come to recognize that in order for industrial research to be effective, it must be understood and organized in a way that is fundamentally different from that of public research institutions.

China, in common with the United States, also recognizes the importance of basic research. Currently, six percent of the Chinese Government's R&D budget is allocated to the support of basic research, a proportion that the Government intends to increase to 10 percent. [NB: In the United States slightly more than 16.3 percent of total national R&D expenditures are currently devoted to basic research.] In part because of differing levels of development, basic research in China is more closely linked to national goals—primarily economic development—than is the case in the United States. Nevertheless, over 40 percent of the basic research currently supported by the National Natural Science Foundation of China is characterized as “pure”, investigator-initiated research.

Although industry has become both the dominant funder and performer of R&D in the United States, the character of industrial research itself has changed. Twenty years ago, industry performed a reasonable amount of basic research. Today, most industrial research focuses is short term and goal oriented. As a result, industry now relies much more heavily than in the past on the basic research performed by universities.

In the United States, university researchers have created many new, high-tech small businesses. In China, a few universities and research institutes of the Chinese Academy of Sciences have also been successful in starting profitable high-tech businesses—with Legend Holding Company perhaps the most prominent example.

Globalization. The trend towards globalization of the economy and R&D is closely linked. Indeed, as was pointed out at the seminar, since one-sixth of all scientific publications are now co-authored by investigators from more than one country, scientific research may be the most global of human activities, and may also be a leading indicator for other fields.

While on balance globalization should be beneficial, potential negative impacts also need to be recognized. Globalization will almost certainly condition bilateral relations between China and the United States. U. S. perceptions of cooperation with China at the governance level will increasingly be seen

through the lenses of globalization. Reciprocally, managing the effects of globalization is one the more challenging tasks facing China's science and technology development strategies, including relations with the United States.

If, as most of not all seminar participants certainly desire, intensified Sino-U. S. R&D cooperation will be one consequence of globalization, policy makers in both China and the United States will almost certainly inquire about relative gains that their respective country's will obtain from such cooperation. Thus, the time may be right to begin to anticipate possible future conflict over relative gains in US-China science and technology relations in order that they not escalate into higher level conflict.

Future Challenges. The first, October 1999 Sino-US Science Policy Seminar constituted a productive start in the exchange of the types of information required as a basis for more extensive and productive R&D cooperation. Importantly, such an information exchange must include a frank exchange of views and perceptions that can result in the removal of actual and perceived barriers to cooperation. But the Beijing seminar was conceived of not as an end in itself, but as the first in a decade-long series of dialogues that will provide opportunities for discussion on specific policy issues of mutual interest and involve a wider range of individuals and organizations in the two countries.

Ideas for possible future events were discussed during the final session of the seminar and being explored in more detail by the joint Sino-U. S. organizing committee. An important criterion for selecting an event, in addition to the intrinsic interest of a topic to both sides, is the likelihood that it can expand the network of institutions in both countries engaged in the dialogues. Events that may possibly be organized within the next 12 to 24 months include:

- A workshop on Sino-U. S. cooperation in biosciences and biotechnology;
- A workshop on engineering education, with perhaps broader participation from East Asia; and
- A Forum on Science in China in Washington, D. C, intended as a showcase for presentations, by Chinese scientists and U. S. scientists familiar with their work, on the current status of science in selected fields and prospects for the future.

Coda. In the first presentation at the seminar, David Hart from Harvard University's Kennedy School of Government suggested a simple, if idealistic outcome for the anticipated decade-long series dialogues between China and the United States; namely, to develop a lively, international civil R&D society.

In the United States, the term "civil society" connotes a private, non-official grouping of individuals with common aims who join together to further their objectives. This formulation, therefore, envisions a future in which scientists and engineers in both China and the United States could enjoy a lively, open, and productive interchange of views leading to useful and mutually beneficial re-

search cooperation. Significant progress has been made towards this end since the United States and the Peoples Republic of China formally initiated scientific exchanges in 1979. However, the underlying rationale for a proposed decade-long series of science policy dialogues is that the time is ripe to permit an accelerated approach.

But of course a lively, international civil society of working scientists and engineers cannot exist or prosper without the active support and encouragement of their governments. Perhaps the principal challenges that emerged from the two days of discussion at Beijing were: (1) how to reduce actual and perceived barriers to international cooperation at both the level of working scientists and engineers and at the governance level; and (2) how to achieve an appropriate and effective balance between the roles of working scientists and their institutions on the one hand, and the roles of governments on the other, in furthering appropriate and productive cooperation.

It may be worth noting that the English word "policy" is derived from the same Greek root as "polis", designating the city. During the third century before the current era, Athenian philosophers and politicians spent a great deal of time debating the attributes of the ideal city, which they regarded as a microcosm of the ideal civil society. But of course they were already three centuries too late to have had any claim to originality. For during the sixth century before the current era, the scholar Kung Fu-tzu, known in the West as Confucius, was already teaching his countrymen the attributes of a just civil society.

Although the principal concern of the October 1999 Science Policy Seminar in Beijing was how to expand and make more effective scientific cooperation between the China and the United States in the 21st century, perhaps we were really asking how the teachings of Kung Fu-tzu, and of the Athenian philosophers who dealt with attributes of the ideal civil society three centuries later, can be adapted to our current knowledge-based, globalized circumstances.

Proceedings of the First Sino-U. S. Science Policy Seminar

A. Overview

China and the United States are both experiencing transitions towards a global, knowledge-based economy (or, more broadly, a global, knowledge-based society) in which the ability to create, manipulate, store, disseminate and exploit knowledge and information will be a major source of economic progress, competitive advantage, and improvements in the quality of life. Advances in science and technology underlie this transition, which in turn offers new challenges to the science and technology enterprise itself. Importantly, knowledge-including scientific knowledge-will also be an increasingly significant factor in relations among nations.

Against this background, the National Natural Science Foundation of China (NSFC) and the U. S. National Science Foundation (NSF) organized a Sino-U. S. Science Policy Seminar, conceived of as the first in a decade-long series of science- and policy-related dialogues among scientists and engineers, policy makers, and policy scholars in China and the United States. The seminar took place in Beijing, People's Republic of China, from October 24-27, 1999, and brought together 12 participants from the academic, industrial and government sectors of each country. Additionally, several younger Chinese scientists and scholars attended the sessions as observers (see participant list, Appendix E). XU Weixuan, Director of the Institute of Policy and Management of the Chinese Academy of Sciences (CAS) and J. Thomas RATCHFORD, Distinguished Visiting Professor National Center for Technology and the Law at George Mason University, served as respective Chinese and U. S. co-chairs of the organizing committee for the seminar. MU Rongping, Director of the Department for Policy Studies, CAS Institute of Policy and Management, and William A. BLANPIED, Director of NSF's Tokyo Regional Office, the principal rapporteurs and co-editors of the proceedings.

The primary objective of the seminar was to explore issues germane to the knowledge-based economy. Many of these issues transcend specific disciplinary interests; all have significant implications for the science and engineering enterprises in the two countries. Underlying this objective is the assumption that a deeper understanding and appreciation of differing perspectives and approaches to issues of mutual concern will improve planning-nationally, bilaterally, and regionally-for the effective and balanced development of science and engineering resources and their utilization in the service of cultural, social and economic goals.

Heightened public expectations for the science and engineering enterprise in both China and the

United States suggest that among the most critical set of problems that the enterprise needs to address on a continuing basis will be how to:

1. improve the effectiveness of knowledge production; and
2. enhance links between knowledge production, dissemination, and application, including application of scientific knowledge itself into broader policy-making processes themselves.

The second of these challenges will be particularly important to the maintenance and improvement of the innovation systems on which economic and social progress depend.

The Sino-U. S. organizing committee for the seminar agreed that the first event in the proposed decade-long series should take a broad-brushed approach by emphasizing the exchange of information and perceptions about a range of issues, some of which might worthy of more detailed exploration in subsequent dialogues. Accordingly, the seminar opened with a plenary session and an associated breakout session devoted to Information and Data Requirements for Policy Making and Research and Development (R&D). A second plenary session and associated breakout session considered Human Resources for Science and Engineering. A third plenary session, held on the second day, was devoted to an exploration of The Changing Character of Research and Development. Conclusions and challenges for the future were discussed in a final plenary session.

B. Information Requirements for Policy Making: Plenary Session I

Two papers were presented in this session:

- “Context for International R&D Cooperation”, by David HART, and
“Technological Innovation: Analysis and Implication for Chinese S&T Policy”, by FENG Xuan and CHEN Jin.

An implicit subtitle for this session might have been, “Information Requirements for International Scientific Cooperation.” That would have been eminently appropriate, in view of the global character of the knowledge-based economy.

David HART’s paper provided a context for much of the discussion during the ensuing sessions of the seminar. He began by reviewing the benefits of cooperation, whether between researchers in different types of institutions in the same country, or cooperation across national borders. Cooperation can generate added value by concentrating more and different minds on a given problem. By bringing a range of skills and resources to bear, cooperation can foster an efficient division of labor and speed up the R&D process. By diversifying the contexts within which the participants in the R&D process are situated, cooperation may raise the likelihood that the results of R&D will be found to be useful and, along the way, generate interesting new problems and methods. However, whereas almost by definition all seminar participants favored increased international scientific coop-

eration, such cooperation should not be undertaken simply for its own sake. Rather, realistic priorities based on shared goals are an essential prerequisite to productive cooperation, whether international or otherwise. Adequate information about the interests of and resources available to potential international partners constitutes a minimal requirement for identifying such mutually beneficial goals and for establishing realistic priorities.

HART's paper went on to consider barriers to effective international research cooperation. Two of the most obvious at the level of working scientists and engineers are language and the cost of communication. While advances in information technology have dramatically reduced this second barrier, there is no adequate substitute for extended, hands-on face-to-face interactions that require people to travel to one another's labs.

The paper stressed the frequently subtle barrier of ignorance. It is difficult for busy researchers to know what is going on elsewhere that may be of interest, particularly beyond their own narrowly defined specialties and the institutions and places with which they are most familiar. Ignorance goes hand-in-hand with fear. Researchers have a lot riding on their research; reputations, careers, and families.

HART suggested that despite these barriers, researchers will choose to cooperate more often than not, when given the chance. The spirit of risk-taking and of internationalism remains widespread and deeply-felt in the science and engineering community.

Barriers to international cooperation are also present at the governance level, which HART defined as encompassing those individuals and organizations that shape R&D choices, including funders, employers, regulators, and lawmakers. These "governors" may be ignorant of distinctions among different types of R&D and wall off excessively broad areas from cooperation. They may be ignorant of the potential gains from cooperation. The issue of opportunity costs, too, appears at the governance level and in a more potent way than at the working level.

HART's paper noted that a special set of barriers relates to the governance of projects that are designed as cooperative efforts, particularly "big science" projects. One challenge is to devise goals for such projects that are defensible to governors on all sides. While these justifications need not always be made in the same terms to each partner, they should at least be compatible with one another.

HART concluded by suggesting why it is essential to work on reducing these barriers; namely, because of the extraordinary opportunities for cooperation that exist now and in the near future. The diffusion of R&D capabilities around the world, the explosion of scientific and technical fields, the breakdown of established institutional boundaries (like those between universities and corporations in the United States), and the decreasing costs of electronic communication, exponentially expand the forms of activity that might be explored through cooperative R&D. The purpose of public policy with respect to R&D cooperation, then, should not be to maximize the level of cooperation. In-

stead, its purpose should be to enhance the gains and reduce the costs of cooperation, whether it be across institutional boundaries or national borders.

FENG Xuan and CHEN Jin's paper summarized the results of an innovation survey of 3346 large and medium sized industrial enterprises in Beijing, Liaoning Province, Harbin, Shanghai, and Jiangsu and Guangdong Provinces. Among these enterprises, 1867 were state-owned, 208 were of the adopted stock system, 539 were joint ventures, and 732 were private firms. This sample is typical for the entire country. The survey focused on the current situation for technological innovation in China using the indices defined by the OECD's Oslo manual for human resources, equipment, innovation type and ratio, innovation novelty, means of innovation, cost structure of innovation, and innovation results.

One important result of the survey was that overall innovation performance in state-owned enterprises is considerably less than in all other types. Importantly, the joint ventures surveyed produced the largest proportion of new international products and accounted for 23.3 percent of the total sales of the entire sample. In contrast, state-owned enterprises had the smallest proportion of new international products and accounted for only 9.5 percent of total sales.

FENG and CHEN's paper concluded with several recommendations for incorporating innovation more effectively into China's science and technology policy. First, concrete and specific guidelines should be given for effective innovation, rather than overly general and universal guidelines. For example, state enterprises should not only emphasize technological innovation, but also institutional and cultural innovations that have been incorporated into other types of enterprises.

Second, more technological innovation should be provided by the enterprises themselves and national science and technology policy should offer incentives to this end. Firms need to invest more in R&D. Additionally, they need to improve their R&D facilities and enhance the level of their R&D workforce.

Finally, science and technology policy needs to be based on a clear recognition that the essence of technological innovation is to link science, technology, production, and marketing. To this end, government policy should emphasize international cooperation as an essential means for strengthening those links.

An important objective of the Beijing seminar was to provide an occasion for information exchange between the Chinese and U. S. participants from several types of organizations about:

- their current science policy-related interests and concerns, separate as well as shared;
- the principal challenges each side perceives both in advancing their separate national science policy interests and in seeking areas for closer cooperation; and
- their perceived future science policy goals and directions.

FENG and CHEN's paper dealt with all three points. For example, the status of technological innovation in China and the factors underlying successful innovation are of considerable interest to the country's political and scientific leadership. Adequate information, such as FENG and CHEN's paper reviewed in quantitative detail, will clearly remain essential in formulating policies to promote successful innovation. It is equally clear that the promotion of technological innovation will remain an important future goal for the country. FENG and CHEN's paper was also important in providing the U. S. participants with insights not only into the technological innovation process in China, but also about the current state of knowledge about the innovation process itself. The availability of such information is an essential prerequisite to productive bilateral cooperation, both for understanding the innovation process itself, and in formulating policies to facilitate innovation.

Various categories of international scientific cooperation were referred to during the ensuing discussion, and were also highlighted by John MCTAGUE in his presentation during Plenary Session III. These include: cooperation in planning, constructing and operating large and expensive research facilities, such as particle accelerators, or optical and radio telescopes. They also include major distributed projects undertaken on a worldwide basis, such as genome mapping and sequencing and global change research. As with all effective research cooperation, the scientific communities of cooperating countries must take the initiative for conceptualizing and advancing such projects. However, because of the cost and complexity of such projects, experience demonstrates that governments must also be involved in planning from an early stage.

Despite the prominence of large-scale cooperative research projects, the majority of international research cooperation involves cooperation between individual scientists or small groups from two or more countries, together with their graduate students and postdoctoral scholars. In these cases the role of governments should be limited to encouraging and facilitating the cooperative efforts of the researchers.

Participants agreed that two other important although often-neglected categories of international cooperation deserved more emphasis. The first category involves exchange of information which, of course, occurred throughout the seminar. There was a broad consensus that information exchange on critical science policy issues between appropriate Chinese and U. S. experts needs to be pursued in a more focused, detailed manner.

The second closely related category, illustrated by FENG and CHEN's paper, involves cooperation in developing and refining internationally comparable statistical tools to understand better trends in important national and international aspects of the scientific enterprise.

Both types of cooperation-information exchange and methodological cooperation-need to be initiated and pursued by working scientists. However, neither can proceed without the active encouragement and support of governments.

Data Requirements for Policy Making and R&D: Parallel Breakout Session I

The three papers presented in this session provided good examples of the potential benefits of international cooperation in developing internationally comparable statistical tools for policy making. They were:

“Using National Accounts to Assess the Role of R&D in the U. S. Economy”, by Sumiye OKUBO;

“Methodology for Evaluating of International Competitiveness of High-tech Industries”, by MU Rongping; and

“Indicators of International Science and Technology Cooperation and Interaction”, by Jennifer Sue BOND.

Sumiye OKUBO described a framework for measuring the effects of R&D on economic growth. This framework would treat R&D as an investment across all industries. It provides a methodology for estimating the full rate of return to R&D—the benefits of the entity undertaking R&D, the direct return and, to others, the spillover return. Her project is ambitious and would take several years to carry out. Participants agreed that it is extraordinary that R&D is not routinely treated as an investment. Her paper pointed out again how important it is to remember that analytic categories are often constructed as a result of legal and political decisions, rather than professional or scholarly choices.

MU Rongping also described an ambitious framework that would require substantial funding and effort to implement. In his case, the object of analysis is corporate and industrial competitiveness in the high-technology sector. He described a method for classifying industries as “high-technology” and then listed multiple measures for the analysis. These measures cover the real and potential competitiveness of firms and sectors as well as their environment.

Jennifer BOND drew on her broad knowledge of various types of indicators and indicators methodologies based, in part, on her experience as the director of NSF’s *Science and Engineering Indicators* program and her extensive international cooperative work, to provide a picture of international scientific cooperation in and between the United States and China. She focused particularly on flows of people and production of papers, and her paper thus nicely complemented John MCTAGUE’s paper on “Globalization of R&D” presented in Plenary Session III.

The data presented by BOND show that China is rising in international stature and, while the brain drain from China to the U. S. and other industrialized countries is not reversing, the potential for such a reverse flow may well be emerging. Her presentation also emphasized the essential role that international cooperation has played in advancing indicators methodologies in several critical areas, and pointed to the need for such collaboration in developing new types of indicators useful in the future: e. g. , reliable indicators of international scientific mobility.

C. Human Resources for Science and Engineering: Plenary Session II

Three papers were presented in this session:

“The Knowledge-based Economy & its Challenge to China’s High Education,” by XUE Lan;

“Opportunities for Chinese and American Universities in the Knowledge-based Economy,” by Richard C. ATKINDSON; and

“Strategy Management on Technological Innovation,” by CAO Zhijiang.

XUE Lan’s paper examined the readiness of the Chinese higher education system to educate the needed highly trained scientists, engineers, innovators, and managers for the new knowledge based economy. To move China ahead in the next century, the Chinese higher education system faces three critical challenges: (1) to increase the number of highly trained graduates; (2) to link knowledge generation in the university setting to the applications in the commercial market; and (3) to provide the continuing education needed in a fast moving society continuously generating new knowledge.

FENG Xuan and CHEN Jin’s paper, presented in Plenary Session I, reviewed data demonstrating that among several categories of industrial organizations in China, state-owned enterprises are the least innovative. Yet in Xue’s opinion, the autonomy of Chinese universities remains less than that of state owned enterprises. At the same time, the environment in which universities dramatically changed to one that is highly market oriented.

XUE’s paper pointed to several issues that are grounds for concern about the readiness and capacity of the Chinese higher education system to meet the challenges of the knowledge-based economy. First, limited autonomy of the universities from central government control. Second, limited capacity in the universities, which has a per capita enrollment rate and percentage of the total population over 25 years with higher education resembling the poorest tier of countries, and far lower than that of the highly technical industrialized nations. Hence, there is significant imbalance in the supply and demand for such highly educated Chinese graduates. This results in a third problem as high school education increasingly becomes preparation for university entrance examinations rather than focused on education and the Government mandates increases in admissions without consideration of the ability and capacity of the universities to provide quality education. Fourth, universities do not necessarily train graduates in the fields needed by the new economy. Fifth, there is insufficient Government support to pay the costs of quality higher education and Government imposed limits on tuition precludes this as a source to narrow the gap.

Richard ATKINSON’s paper provided an historical view of the development of the academic base for the knowledge-based economy in the United States as a way of identifying possible themes the Chinese system could consider. He noted that theory had grown up around performance in the United States, resulting in a “new growth theory” which related investments in R&D to economic

growth and identified the important role of Government supported research in the universities in driving this relationship. Federally supported research carried out in the universities has catalyzed private investment in R&D, leading to the creation of new jobs and industry near the universities producing highly trained graduates. Well educated, technologically advanced graduates willing to take risks are available for the innovative, small, entrepreneurial high tech companies that spring up when other local conditions such as the availability of venture capital and accounting and legal services are favorable. It is important to note that universities can play a proactive role in creating this environment—not only in providing well educated graduates, but also in facilitating technology transfer to industry through programs intended to link the knowledge generation in the universities to business opportunities. Government policy can facilitate this, as for example the laws in the United States that gave patent and licensing rights for inventions supported by Federal funds to universities.

ATKINSON suggested that the lesson from his analysis of most relevance to China is the in the recognition in the United States that, in his words, “universities are priceless sources of ideas that can create jobs, give birth to new industries, and stimulate productivity growth”. How this principle is applied may differ between the United States and China.

CAO Zhijiang’s paper traced the history of Legend Holdings, Limited, as one model of this process for China. Eleven technically trained members of the Chinese Academy of Sciences’ (CAS) Institute of Computer Technology founded the company in 1984, with “venture capital” from CAS. Their first product, a Chinese character processing system, was versatile and useful. A decision was made to tailor the product to the non-professional PC user, a market that did not exist in China at the time, rather than seeking to fill mainframe computer needs. The wisdom of this decision is evident in retrospect. Legend has surged ahead in sales and market share in China and the rest of East and South East Asia. Several principles of business have permitted this rapid growth: (1) product development and marketing were closely coordinated; (2) after sales service was geared to customer support; and (3) technical staff engaged customers and learned first hand of customer needs so that product improvement was continuous and geared to the market. The continuing orientation of Legend to integrate high tech R&D into the market is reflected in its allocation of its R&D budget, with 20 percent devoted to basic research, 30 percent to key technology research, and 50 percent to application research for the development of new high tech products.

The personal computer industry is a good example of the possibilities of well organized R&D tailored to marketable products, as sales have taken off all over the world, and at the same time it may be one that is difficult to replicate with such speed and success in other industries. In China, the further maturation of Legend to a public company, owned in part by its employees, is another striking change from the state-owned enterprise model, and very much in line with the situation in the United States and other highly technical industrialized countries.

Several themes emerged in the ensuing discussion. First, there is great potential in distance learning

methods for high tech education, between the United States and China, for example, or from technically advanced, research intensive universities to students elsewhere within China. This is applicable, for example, to the didactic components of biomedical research training, including clinical research methodology, clinical trials, and clinical data collecting. Some of this can be accomplished by internet, teleconferencing and other electronic communication modalities.

Second, peer level training, both national and international, can be a highly effective mechanism for information transfer, supplementing the senior mentor-trainee interaction in a less formal environment. Opportunities for U. S. trainees to work in China alongside Chinese trainees should be fostered, in addition to increasing opportunities for Chinese students to train in U. S. institutions. Relationships developed during training are often sustained lifelong, and are the basis for establishing and sustaining close and trusting research collaborations.

Third, research training should be carried out in the course of conducting research, where methodological tools are applied to the solution of research questions. The opportunity to link theory with practice in the solution of real problems is essential. In the course of developing undergraduate, graduate and post-graduate research training, there must be sufficient resources to carry the burden of frequent experimental failures, and resources to allow trainees to problem solve to get beyond the barriers. Without this there can be but little progress. At the same time, it is necessary to establish some peer review process to review the productivity of training laboratories and centers. In the United States, this is accomplished by the need to renew Federally supported research grants through the competitive peer review process for grants for both research and training.

Three papers were presented in this session:

“The Knowledge-based Economy and Human Resources Mobility”, by CHEN Hao;

“CHU University Role in Regional Development”, by CHU Xuelin; and

“Preparing Scientists and Engineers for the 21st Century”, by Edward PARRISH.

CHEN Hao’s paper was a detailed account of the emergence and evolution of China’s post-doctoral system, particularly as it has developed in the Chinese Academy of Sciences. The post-doc system provides real though still limited mobility within China’s scientific community, a significant break from the past.

CHU Xuelin’s paper was a thoughtful discussion of the multiple roles of the university in economic and social development, from generating to disseminating knowledge, and from training personnel to energizing local culture. Particularly valuable was the paper’s focus on *regional* development dynamics.

Edward PARRISH’s paper started with a comprehensive discussion of the changing nature of the global economy and thus the necessity to change the education of engineers. It went on to present the model of Worcester Polytechnic Institute, which emphasizes flexibility, teamwork, and intercultural experience in addition to the technical training.

D. Changing Character of R&D: Plenary Session III

Four papers were presented during this session:

“China’s Basic Research at the Turn of the Century and its National Goals”, by ZHANG Cunhao;

“Globalization of R&D”, by John MCTAGUE;

“Changing Role of Industrial R&D”, by FANG Aihua; and

“The Evolving Face of Science and Technology Policies,” by Gerald HANE.

ZHANG Cunhao’s remarks indicated that in several important ways, Chinese thinking about basic research is both consistent with, and different from, thinking in the United States. The differences stem in part from China’s level of economic and technological development and from the characteristics of its national research priorities and system of research institutions.

ZHANG’s paper noted that China’s basic research goals are intended to address five main scientific and technological development objectives; namely:

1. preparing for future high technology development in ways which would allow China to leapfrog into leadership in the development of future technological trajectories and in exploiting future industrial opportunities (e. g. , work in nanoelectronics);
2. aiding in the upgrading, or renovation, of traditional industries (e. g. , work in seed breeding, geophysical work in oil prospecting);
3. providing radically new ideas for reconceptualizing practical problems (e. g. , mathematical applications in finance);
4. generating truly original ideas which may not have immediate practical application; and
5. serving higher education and the advanced training of high level manpower.

Expenditures for basic research in China have increased steadily since the National Natural Science Foundation of China (NSFC) was founded in 1986, with the rate of increase being most apparent since 1992. Basic research support is scheduled gradually to come to occupy a larger share-10 percent, up from its present six percent of the nation’s R&D spending. [NB: in the United States, basic research currently accounts for slightly more than 16 percent of total national R&D expenditures.] Zhang also noted that, with the initiation of the National Basic Research Program (“973”- a program of targeted, mission-oriented, top down, “basic” research), the share of NSFC funding for “pure,” investigator initiated research has been adjusted upward from 30 percent to 42.5 percent of NSFC research support. In this sense, NSFC is playing a role analogous to the “balance wheel” function that Richard ATKINSON attributed to the U. S. National Science Foundation in his presentation during Plenary Session II.

John MCTAGUE’s presentation explored the reasons for the globalization of R&D and presented a

number of measures of how extensive the process has become. Using data from the U. S. National Science Board's *Science and Engineering Indicators-1998*, MCTAGUE illustrated the trends in globalization as seen in corporate R&D patterns, big science projects (of both the central facility and distributed categories), and in "ordinary", small-scale research. The reasons for globalizing trends differ somewhat among the three areas, but common features include:

- the diffusion of scientific capabilities around the world;
- higher standards of living and new market opportunities in parts of the world beyond the OECD countries;
- the worldwide search for talent by industrial firms and the worldwide search for collaborators by research scientists; and
- the ease of travel as a result of relatively low cost transportation and the advent of virtually costless and instant communications and access to data via the Internet.

MCTAGUE suggested that the trends he identified are almost certain to continue into the foreseeable future, making physical distance an increasingly less important factor in scientific cooperation and making scientific research, perhaps, "the most global of human activities." At the same time, the high costs of industrial R&D are forcing both increasing cooperation among competitors and increasing international industrial concentration, as firms merge and consolidate (as in the automobile industry) in search of economies of scale. Thus, patterns of international science and technology will show both new forms of centralization as seen in industrial consolidation and in some "big" science activities and new types of decentralization in a spatially dispersed, distributed community linked via electronic communication.

FANG Aihua's paper considered the changes that need to take place in China's national system of innovation if the country's industrial R&D activities are to contribute more effectively to its economy. Unlike the situation in the United States, Japan and Western Europe, the central government still provides the majority of the support for R&D in China. Most of those funds go to public research institutions rather than enterprises. Likewise, most Chinese scientists and engineers work in public research institutions or universities located in large cities.

As is true in other countries, most researchers in public research institutions and universities lack either the training or motivation to choose research topics or research directions with a commercializable end product or process in mind. Successful industrial innovation, as has been demonstrated by many studies, requires that research, product development, and marketing should be closely coupled. But until recently and with some notable exceptions (e. g. , Legends), neither researchers nor managers in Chinese enterprises (particularly state-owned enterprises) have been trained or encouraged to think in those terms. Nor are those enterprises organized to facilitate such close coupling.

ZHANG's paper pointed out that this situation has led to a serious brain drain. Many state-owned enterprises have not provided sufficiently challenging work or adequate facilities to their young engi-

neers. As a result, many have joined private companies or emigrated (e. g. to Singapore) so that the average age of engineers at many large state-owned enterprises has actually increased during the past 20 years.

With economic reform and the opening of the country to foreign investment, the situation regarding industrial R&D has improved. For example, in 1988, state-owned enterprises accounted for less than 14 percent of all patents granted in the country; today they account for almost 30 percent. ZHANG made several recommendations both for the education and training of engineers and the organization of research within enterprises that they believe can lead to further improvements.

Gerald HANE's presentation began by noting that over the decade of the 1990s, a shift in the shape of the science and technology enterprise in the United States has brought about a continuing evolution of the country's science and technology policies. Important elements that underlie this shift include a substantial increase in industrial investments in research and development, more modest growth in the U. S. government's investment in research and development, and the rapid expansion of venture capital investments. In response, government policy has given priority to the use of public-private partnerships as a means of meeting societal goals, to supporting long-term basic research, to improving the diffusion of innovations, and to promoting linkages such as those between universities and industry.

HANE emphasized that university-industry research partnerships have gained greater attention over the decade, with interest heightened by the increase in venture capital activities. Here the principal role of the government has been to provide a legal framework for these partnerships. One challenge is to ensure that these partnerships energize the education and research functions of universities without compromising openness and the pursuit of knowledge.

E. Highlights of Principal Discussion Themes

The prepared presentations and ensuing discussions in the plenary and parallel breakout sessions at the October 1999 science policy seminar in Beijing amply justified the now familiar contention that the transition to a knowledge-based economy in both China and the United States is being driven by science and technology. More important for the purposes of the seminar, the demands of the knowledge-based economy are changing the character of the science and technology enterprise itself, at both the national and international levels.

The intimate coupling between the knowledge-based economy and national science and technology enterprises, evident in presentations and discussions throughout the seminar, was demonstrated most explicitly during Plenary Session III on The Changing Character of R&D. Several such changes were identified, primarily:

1. Changes in the roles of, and relationships among, the principal supporters and per-

- formers of R&D;
2. Changes in the capabilities required of the science and technology workforce and the resultant impacts on the institutions that will train and utilize the workforce of the 21st century;
 3. The critical need for adequate and reliable quantitative information (including new types of statistical indicators) to gauge the multiple, changing aspects of the global, knowledge-based economy; and
 4. Globalization of R&D and its impacts on national science and technology systems and on international R&D cooperation.

Roles and Relationships. In his opening remarks as chair of the second half of Plenary Session III, Charles LARSON highlighted the growing importance of U. S. industry as both principal funder and principal performer of R&D. According to the most recent estimates, U. S. industrial investment in R&D in 1999 are expected to be \$ 166 billion, up 12 percent over the estimated \$ 148 billion that was invested in R&D by industry during 1998. This \$ 166 billion represents 68 percent of the \$ 245 billion total R&D effort in the U. S. in 1999. The U. S. Government is expected to provide \$ 68 billion for R&D in 1999, or 28 percent of the total, while universities are expected to provide \$ 6 billion of their own funds (2 percent) and non-profit organizations is expected to provide \$ 5 billion (2 percent). In addition to its own funds of \$ 168 billion for R&D, industry expected to receive some \$ 20 billion from the Departments of Defense and Energy, NASA, and other Government agencies for R&D in 1999. Thus industry will perform some \$ 188 billion worth of R&D this year, or 77 percent of the total R&D effort in the United States.

U. S. industrial R&D investments, measured in current dollars, have increased 71 percent over the past five years and 126 percent over the past ten. These increases represent double-digit annual growth rates; in only three of the past ten years have the increases been less than 10 percent. Of the \$ 166 billion performed by industry on R&D in 1999, 71 percent will be for development activities, 22 percent will be for applied research, and approximately 7 percent will be for directed basic research. Directed basic research has increased from \$ 6.1 billion in 1994 to \$ 10.9 billion in 1999, an increase of 79 percent, or a rate of nearly 15 percent a year. Applied research has also grown significantly, rising from \$ 19.4 billion in 1994 to an estimated \$ 37.0 billion in 1999, an increase of 91 percent.

U. S. companies are also investing more in R&D abroad. A recent U. S. Commerce Department report, *Globalizing Industrial R&D*, indicated that R&D expenditures in the United States by foreign-owned companies tripled from \$ 6.5 billion in 1987 to \$ 19.7 billion in 1997. U. S. companies also increased their R&D spending in other countries, rising from \$ 5.2 billion in 1987 to \$ 14.1 billion in 1997.

While the prominence of the U. S. Government as a supporter of R&D has continued to decline relative to that of private industry, its importance in encouraging in formulating and implementing na-

tional policies for effective investments has become more important. Government policies now aim to use public-private partnerships as means for meeting societal goals, and to provide a legal framework for these partnerships. Government also continues to play the vital role as the principal supporter of basic research in universities and other non-profit institutions.

In China, the central government remains the principal supporter of R&D, and the bulk of R&D funding has traditionally gone to public research institutions and universities in major cities rather than to enterprises. The study reported in FENG Xuan and CHEN Jin's paper in Plenary Session I shows that the overall innovation performance in state-owned enterprises is considerably less than in all other types; e. g. , joint ventures and private companies. Moreover, state-owned enterprises have the smallest proportion of new international products and accounted for only 9.5 percent of total sales. This situation is showing some improvement, as China's policy makers take steps to promote more R&D investments in enterprises. They also have come to recognize that in order for industrial research to be effective, it must be understood and organized in a way that is fundamentally different from that of public research institutions.

Although industry has become both the dominant funder and performer of R&D in the United States, the character of industrial research itself has changed. Twenty years ago, industry performed a reasonable amount of basic research. Today, most industrial research focuses is short term and goal oriented. As a result, industry now relies much more heavily than in the past on the basic research performed by universities.

The success of the U. S. system can be traced to Federal funding of basic research in universities. However, the emphasis on investigator initiated research proposals and the peer review system in which peer working scientists judge the merit of proposals for funding are essential for promoting creativity and quality. The process is a continuous competitive one in which merit, innovation, and relevance remain the major criteria for support.

In the United States, university researchers have created many new, high-tech small businesses themselves. In China, a few universities and research institutes of the Chinese Academy of Sciences (most notably Legends) have also been successful in starting profitable high-tech businesses.

The Science and Technology Workforce. In his introductory remarks as chair of Plenary Session II, R. Thomas WEIMER suggested that human resources development, particularly in engineering and the applied sciences, is one of the most important challenges that both China and the United States face. Industrial employers are seeking university graduates who are broader and more interdisciplinary in nature than were their predecessors. Industry needs people with the ability to think logically, adapt quickly, work in teams, communicate their results succinctly, and graduates with a yearning for lifelong learning to keep them ahead of technical obsolescence.

Perhaps the most important of the evolving demands on research universities is to become not just

creators of knowledge and knowledgeable individuals, but also to expand their role and methods in the rapid diffusion of knowledge. This is not necessarily a new role for some universities in some disciplinary areas for example, agricultural research in the United States but for others it is a dramatic break from their long held views of the role of their universities in human resource development and their role in the innovation system. While executed regionally (as in the case of California, highlighted in Richard ATKINSON's paper in Plenary Session II), these changes in the ways which universities transfer knowledge aggregate nationally, and promote more rapid national economic growth.

XUE Lan's paper in Plenary Session II suggested that reform is urgently required if the Chinese higher education system is to become capable of reorienting education to the output-demand needs of a knowledge based economy. To accomplish this will require that universities be given more autonomy in several areas, including academic programs and curriculum, administration, and fiscal matters. Attention will need to be directed to the education of a managerial group. Quality of education will need to be insured by development of standards and accreditation procedures. And of major importance, private universities will need to be encouraged, including universities with international linkages.

The trend toward university-industry cooperation beginning to emerge in China has obvious positive implications for the dissemination and application of scientific and technological innovation. But should there be limits to university engagement in business activities, given industry's interest in short-term results and the mission of universities to promote long-term basic research? CHU Xuelin mentioned in his presentation in Parallel Breakout Session II that the University of Science and Technology in Hefei has created hundreds of companies. How does that affect the basic research and educational missions of the university?

Universities can contribute a great deal to the development of their local regions, as Richard ATKINSON's presentation in Plenary Session II demonstrated in the case of California. In China, the Science and Technology University in Hefei provides a good example. However, most good universities in China are concentrated in a few cities. How does that influence the national pattern of innovation? What can be done to encourage the coordination and spread of their contribution to the national economy?

The Worcester Polytechnic Institute model presented by Edward PARRISH in Parallel Breakout Session II addresses many challenges for engineers in the new economy of the 21st century. Although it is probably not practical for Chinese universities to copy the model, it suggests ways to improve the training of engineers and university students in general. Rather than having students specialize as soon as they begin college, Chinese universities may benefit from introducing the concept of liberal arts education. Chinese colleagues say that some universities are beginning to think about such changes.

The free and efficient allocation of human resources for science and technology remains a problem for China. The country's relatively recent post-doctoral system has had some success in promoting mobility among different institutions and sectors. But other types of policy initiatives may also be required.

Importance of Quantitative Information. The three papers presented in Parallel Breakout Session I demonstrated the critical importance of measurement and methodologies both for policy making and for research in science and technology policy. Policy makers in both the public and private sectors rely on reliable, internationally comparable science and engineering indicators data in making decisions on critical issues, such as resource allocation among various fields of science and priority setting for specific types of projects. Additionally, science policy scholars depend on this type of work for developing policy recommendations. Their analyses are only as good as the underlying data. There is no substitute for public funding and public provision of such data.

It is essential to examine, periodically and critically, the question of whether the indicators data being developed intersect sufficiently with what policy-makers need. This is not to say that those who develop quantitative science and engineering indicators should tailor all data production to serve policy-makers. Autonomous research deserves a place. But it is essential to make sure that policy makers are among the users who find the data useful to have. To this end, the National Science Foundation's Science and Engineering Program carries out periodic customer surveys as a means for determining the current and probable future needs of users in government, industry and academia.

A great deal more attention needs to be paid to measuring the outputs of R&D and the outcomes that reflect the impact of science and technology on society. A very good job has been done on measuring the inputs to science and technology, but that's not what policy-makers care most about. Papers presented at the seminar provide useful frameworks to begin work on measuring the outputs of R&D and its impacts on the economy and society. At the same time, it is essential to acknowledge that in moving from inputs to outputs and especially to outcomes, the error bands around measurements inevitably grow.

The papers presented at the seminar suggest also the importance of utilizing multiple measures no matter what subject is being. International collaboration can be a particularly effective way to develop better measures of R&D output and outcomes-data that would be particularly useful for policy making.

Globalization of R&D. John MCTAGUE concluded his presentation during Plenary Session III by suggesting that since one-sixth of all scientific publications are now co-authored by investigators from more than one country, scientific research may be the most global of human activities, and may also be a leading indicator for other fields. In addition to MCTAGUE's, globalization, was an important if implicit subtheme in many of the other presentations at the seminar and in ensuing discussions. Although most participants tacitly assumed that the impacts of globalization would, on

balance, be positive, potentially negative impacts were also recognized.

The discussion that followed MCTAGUE's presentation touched upon the implications of the globalization of R&D for Sino-U. S. cooperation in science and technology. Globalization will almost certainly condition bilateral ties. U. S. perceptions of cooperation with China will increasingly be seen through the lenses of globalization. On the other hand, managing the effects of globalization is one the more challenging tasks facing China's science and technology development strategies, including relations with the United States. In particular, a major concern is how China can attract foreign corporate investment in research without having its research system become simply an appendage of the innovation systems of multinational firms.

Concern for the possible costs of globalization is evident in the United States as well. Some observers are questioning if trends such as the growth of foreign investment in U. S. R&D, and the large number of overseas students coming to U. S. universities, pose dangers that intellectual assets will be drained from the country. Similarly, questions have been asked about the high proportion of foreign born students in science and, especially, in engineering graduate programs, and about the growing reliance on foreign-born scientists and engineers by U. S. industry.

Richard SUTTMEIER noted that in spite of mutual gains, the political processes which shape the environment for international cooperation often focus on "relative gains" whether one side gets disproportionate benefits relative to the other.

The time may be right to begin to anticipate possible future conflict over relative gains in U. S. -China science and technology relations in order that they not escalate into higher level conflict, as happened with U. S. science and technology relations with Japan during the 1980s. In the relative gains conflicts with Japan, much attention was focused on the issue of "asymmetrical access," where Japanese investigators had access to areas of U. S. R&D while U. S. investigators could not access comparable areas of Japanese R&D. These problems were, in part, a reflection of the different institutional arrangements and programmatic emphases in the two countries.

SUTTMEIER asked whether we could expect similar kinds of problems to develop in U. S. relations with China, or whether conditions in the early 21st century, as a result of the positive trends noted by MCTAGUE (e. g. , the drastically reduced costs of collaboration, the international flows of human resources in science and education) will make the problems of institutional and programmatic asymmetry less of an issue. The differences in approaches to basic research, as indicated in ZHANG Cuhnao's remarks in Plenary Session III, point to asymmetries in institutions and program assumptions, and may suggest the need for anticipatory discussions on how conflicts from asymmetries can be avoided, and assumptions harmonized.

F. Challenges for the Future

Isn't it a pleasure to make practical use of the things you have studied? Isn't it a pleasure to have an old friend visit from afar?

Kung Fu-tzu (Confucius)

The first, October 1999 Sino-U. S. -Science Policy Seminar constituted a useful beginning in the exchange of the types of information (including, importantly, a frank exchange about information on actual and perceived barriers) that have the potential of leading to more extensive and productive bilateral cooperation. But the work begun in Beijing needs to be expanded to include many other individual participants and organizations in both China and the United States, and also deepened to encompass more detail.

During the concluding session of the seminar, participants reviewed the principal issues, themes, and ideas from the prepared presentations and the ensuing discussions in order to identify tentative topics that could serve as a basis for future events in the proposed decade-long series of Sino-U. S. science policy dialogues. These included:

- Prospects for expanded cooperation in specific areas of science and technology;
- Innovation and industrial research, including distinctions between industrial and public research institutions;
- Science and engineering workforce issues, including graduate education in science, and training of engineers for the global, knowledge-based economy;
- Public understanding of science; and
- Data for policy making, including data on human resources for science and engineering, and indicators of human resources mobility-intersectoral as well as international.

Participants agreed that one important objective of the proposed dialogues, in addition to exchanges of information and perspective, should be to engage a wider range of government and non-government institutions in both countries. Although the National Science Foundation and the National Natural Science Foundation of China will continue as the organizations responsible for events in the series, other organizations should also be closely involved and, in some instances, should assume primary responsibility for specific events. Examples of appropriate organizations include, on the U. S. side, other Federal agencies such as the National Institutes of Health. Appropriate private sector organizations include the Industrial Research Institute; the National Academies of Science and Engineering; and a variety of professional science and engineering societies. Important Chinese organizations that ought to be involved include: the Ministry of Science and Technology; Chinese Government mission-oriented bodies such as the Ministry of Health; a wider range of institutes of the Chinese Academy of Sciences; and the Chinese Association for Science and Technology. Topics for future workshops ought to be selected, in part, with a view towards establishing a network of organi-

zations which participate in the dialogue.

In addition to organizing workshops in which a relatively small number of experts from the two countries engage in exchanges of information and perspectives, there would be considerable merit in a larger forum in which leading Chinese scientists and prominent U. S. scientists familiar with their work made presentations to invitees from the U. S. science policy community on the current status of their fields and their plans for the future.

Against this background, possible Sino-U. S. events to be organized within the next 12 to 24 months are:

- A workshop on cooperation in biosciences and biotechnology;
- A workshop on engineering education, with perhaps broader participation from East Asia; and
- A forum on Science in China, to be held in Washington, D. C.

G. Coda

David HART's presentation during Plenary Session I suggested a simple, if idealistic goal for the decade-long series of science policy dialogues that China and the United States plan to organize; namely, to develop a lively, international civil R&D society.

In the United States, the term "civil society" connotes a private, non-official grouping of individuals with common aims who join together to further their objectives. HART's formulation, therefore, envisions a future in which scientists and engineers in both China and the United States can enjoy a lively, open, and productive interchange of views leading to useful and mutually beneficial research cooperation. Significant progress has been made towards this end since the United States and the Peoples Republic of China formally initiated scientific exchanges in 1979. However, the underlying rationale for a proposed decade-long series of science policy dialogues is that the time is ripe to permit an accelerated approach.

But of course a lively, international civil society of working scientists and engineers cannot exist or prosper without the active support and encouragement of their governments. Perhaps the principal challenges that emerged from the two days of discussion at Beijing were: (1) how to reduce actual and perceived barriers to international cooperation at both the level of working scientists and engineers and at the governance level; and (2) how to achieve an appropriate and effective balance between the roles of working scientists and their institutions on the one hand, and the roles of governments on the other, in furthering appropriate and productive cooperation.

It may be worth noting that the English word "policy" is derived from the same Greek root as "polis", designating the city. During the third century before the current era, Athenian philosophers

and politicians spent a great deal of time debating the attributes of the ideal city, which they regarded as a microcosm of the ideal civil society. But of course they were already three centuries too late to have had any claim to originality. For during the sixth century before the current era, the scholar Kung Fu-tzu, known in the West as Confucius, was already teaching his countrymen the attributes of a just civil society.

Although the principal concern of the October 1999 Science Policy Seminar in Beijing was how to expand and make more effective scientific cooperation between the China and the United States in the 21st century, perhaps we were really asking how the teachings of Kung Fu-tzu, and of the Athenian philosophers who dealt with attributes of the ideal civil society three centuries later, can be adapted to our current knowledge-based, globalized circumstances.

Plenary Session I: Information and Data Requirements for Policy-making

The Context for International R & D Cooperation

David M. HART*

Participants in this seminar will need little convincing that R&D can and should play a major role in the pursuit of such public goals as prosperity, public health, environmental protection, and military security. The case that R&D can often be made more effective through cooperation, including international cooperation and cooperation among diverse sorts of institutions, is also likely to be accepted among us, but deserves elaboration. Cooperation can generate value in several ways. By concentrating more and different minds on a given problem, it may increase the chance of solving that problem. By bringing a range of skills and resources to bear, it can foster an efficient division of labor and speed up the R&D process. By diversifying the contexts within which the participants in the R&D process are situated, cooperation may raise the likelihood that the results of R&D will be found to be useful and, along the way, generate interesting new problems and methods.

Of course, cooperation only adds value up to a point. Eventually, the costs of administration and coordination overwhelm the gains of cooperation. In some contexts, notably military R&D and commercial product development, cooperation can undermine the achievement of the larger goal to which R&D contributes. And, from a more removed perspective, too much cooperation may lead to "groupthink," the convergence on the same ideas of too many of those who know something about a subject and the consequent discounting of valuable alternative perspectives. The purpose of public policy with respect to R&D cooperation, then, should not be to maximize the level of cooperation. Instead, our purpose should be to enhance the gains and reduce the costs of cooperation, whether it be across national borders or institutional boundaries, while preserving diversity and avoiding groupthink within the R&D system.

The people who ultimately determine whether cooperation is worthwhile are the researchers themselves. They decide whether to send that E-mail, make that trip, change what they are doing in the lab, or share their best ideas. The direct participants in cooperation must perceive the prospect

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of mutual gains for it to work. Even in the absence of barriers imposed by others (which I will take up below), barriers at the working level often impede cooperation. Public policy-makers should try to ensure that researchers are aware of as broad as possible an array of potentially valuable partners and that they have the capacities to build the partnerships that they find appropriate. In short, we should be cultivating a thriving civil society among researchers who cooperate autonomously as well as within officially mandated programs.

One simple and profound barrier at the working level is language. Americans, for instance, are dismally ignorant of other languages. U. S. researchers are not likely to know of results not published in English language journals, leaving them ignorant of an expanding world of technical people and ideas. Even when they are aware of potential collaborators abroad, they may fear having to put more effort into communication than the benefits of cooperation are likely to warrant. Clearly, the U. S. can do a better job equipping its researchers in this regard. Yet, as this seminar itself demonstrates, the burden on non-English speakers is much higher, since English is by far the most widely used language in science and technology.

If the language barrier is surmounted, others may appear at the working level. The cost of communication, particularly internationally, can inhibit cooperation. While advances in information technology have dramatically reduced this barrier for data, voice, and even video communication, face-to-face interactions that require people to travel to one another's labs are and will continue to be important. There is no adequate substitute for extended, hands-on visits.

A more subtle barrier is that of ignorance. It is hard for busy researchers to know what is going on elsewhere that may be of interest, particularly beyond their own narrowly defined specialties and the institutions and places with which they are most familiar. Yet, boundary-crossing cooperation may well be the most valuable form of cooperation of all. Ignorance of a different sort centers on assessing the suitability for cooperation of unfamiliar sorts of potential partners, even when one knows that their work may fit with one's own from a technical point of view. Opportunities for cooperation may be passed up because of ignorance about the potential partner's background, the rules that govern his institution, and the resources available to him. Differences in perceived status, perhaps better described as prejudice rather than ignorance, can also impede cooperation, as when academics look down their noses at industrial researchers.

Ignorance and prejudice go hand-in-hand with fear. Researchers have a lot riding on their research: reputations, careers, families. The known benefits of continuing to do what one is doing are not easily traded for the unknown benefits and sometimes substantial costs of cooperative R&D. Researchers may fear losing time, losing out on local opportunities, and even losing credit for their ideas to those with whom they might otherwise work.

Language, the costs of communication, ignorance, prejudice and fear are all real and important barriers to R&D cooperation, particularly international R&D cooperation, at the working level. Yet,

my guess is that, by and large, researchers will choose to cooperate more often than not, when given the chance. The spirit of risk-taking and of internationalism remain widespread and deeply-felt in the scientific and technical community.

Many of the barriers that may impede R&D cooperation at the working level are also present at what I will call "the governance level." By governance level, I mean to encompass all those people and organizations that shape R&D choices (whom I will refer to generically as "governors"), including funders, employers, regulators, and lawmakers. Ignorance and fear, for example, are far from unknown among governors. As at the working level, these barriers at the governance level are sometimes understandable and appropriate. For instance, while it may not always be true that "only the paranoid survive," as the title of Intel chairman Andrew Grove's book puts it, fierce competition to capitalize on the results of R&D in industry and the military justify fear of potential and actual competitors. Often, however, decision-makers at the governance level create unnecessary barriers.

They may be ignorant of distinctions among types of R&D and wall off excessively broad areas from cooperation. They may be ignorant of the potential gains from cooperation. They may fear punishment from those who are more ignorant in these regards, such as bosses, oversight committees, and voters, and hence take the most cautious approach to cooperation.

The issue of opportunity costs, too, appears at the governance level and in a more potent way than at the working level. Governors are asked to supply funds for travel and other costs that might be spent instead on any number of other things, including the work of other researchers. There is a chance as well that the researchers whose cooperation the governors endorse will be distracted from the main mission of the governors' enterprise and even depart in a brain drain.

Most of the discussion to this point assumes a form of cooperation that emerges out of existing projects of researchers. Another set of barriers relates to the governance of projects that are designed as cooperative efforts, particularly "big science" projects. One challenge is to devise goals for such projects that are defensible to governors on all sides. While these justifications need not always be made in the same terms to each partner, they should at least be compatible with one another. A second challenge is to assure the potential partners that each will get a "just return" (as the Europeans put it) on the resources that they invest. Contracts and procedures, some of which can be quite stultifying, are often put in place to provide this assurance. Goals, results, and governing arrangements may well be assessed and re-assessed over the life of the project, particularly when annual appropriations of government funds are involved (as is almost always the case when the U. S. government is one of the partners). Thus, a third challenge is the construction of a flexible decision-making process that can adapt to changes in the environment surrounding the project as well as to scientific and technological opportunities and constraints that emerge during it.

I have concentrated on barriers to R&D cooperation across national boundaries and among different

kinds of institutions. These barriers focus our minds on *what* needs to be done.

We would be remiss, however, if we did not remind ourselves *why* we ought to work on reducing these barriers; extraordinary opportunities for cooperation now and in the near future. The diffusion of R&D capabilities around the world, the explosion of scientific and technical fields, the breakdown of established institutional boundaries (like those between universities and corporations in the U. S.), and the dropping costs of electronic communication exponentially expand the forms of “fusion” (as Fumio Kodama calls it) that might be explored through cooperative R&D. Who can say which form of cooperation will be most fruitful? Above all, the emergence of global problems that require global solutions demand that we attend to this set of problems. Policy deliberations should focus on the conditions that enable researchers to cooperate on their own as well as on top-down cooperative R&D initiatives that can, if managed well, take on a life of their own.

Technological Innovation: Analysis and Implication for Chinese S & T Policy

FENG Xuan and CHEN Jin *

Abstract Technological innovation is the key factor for competitiveness of enterprises, whether in the public sector or the private sector. This paper, based on the statistical analysis of 3346 large and medium industrial enterprises in China, tries to explore the state of art of technological innovation in China, and some basic rules on the technological innovation. Some inspirations for S&T policy are also provided.

Keywords technological innovation, statistical analysis, large and medium enterprises, S&T policy.

I. INTRODUCTION

Science and Technology (S&T) policy is one of the main parts of the national policy system. With the fast development of S&T, especially rapid progress of the information and communication technology (ICT) and the emergence of the Knowledge Economy, S&T policy will play a more and more underpinning role in the national development. Technological innovation is the key for national wealth creation and corporate growth, S&T policy is expected to give more support and incentive to the innovation competence of both the nation and enterprises.

Traditionally, S&T policy has always made by the top-down, but a more rational and practical policy need to balance the top-down and the bottom-up approach. In this paper, we try to provide some innovation-oriented S&T policy for China mainly based on bottom-up method.

3346 large and medium industrial enterprises in Liaoning, Jiangsu, Guangdong Provinces and Beijing, Shanghai, Haerbin cities are our survey focus, among the enterprises, 1125 of them are extra-large enterprises, 2221 are large and type one enterprises. In the view of the corporate system,

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1867 of them are state-owned (accounting for over 50%), 208 of them are adopted stock system, 539 of them are joint ventures, and 732 of them are private ones. As the enterprises we selected are the typical ones in China (some of them are large and famous enterprises and international groups), the state art of the technological innovation in China can be gotten by studying them.

These statistics are very typical because the total revenue of the sampling firms is 67.77 billion RMB Yuan, and the number of sampled firms accounts for 14.5% of the total large and medium firms in China (the employees account for 13.6%, profit for 22.0%). And the total data are around half million, which cost 3 years heavy work.

The framework of this statistical analysis is based on the Oslo Manual, with some adjustment, the industrial characteristics, enterprise scale, economic system type, R&D institution, import & export right, marketing network and quality etc are the main indicators we observed. We also focus on the current situation of technological innovation in China by using the index of human resource, equipment, innovation type and its ratio, novelty of innovation, means of innovation, cost structure of innovation and innovation results.

II. INDUSTRIAL CHARACTERISTICS OF INNOVATION IN CHINA

In general, innovation is the key for the industrial competitiveness, but there exists differences among industries. According to our statistics, 71.46% of the large and medium enterprises have normal innovation activities. And enterprises in medicine manufacturing, petrochemical, metallurgy, mechanical and equipment, electric, electronics and instrument industry have higher innovation levels, while enterprises in food processing, clothing, leather, fur and paper-making industry are not so active in innovation (see Fig. 1).

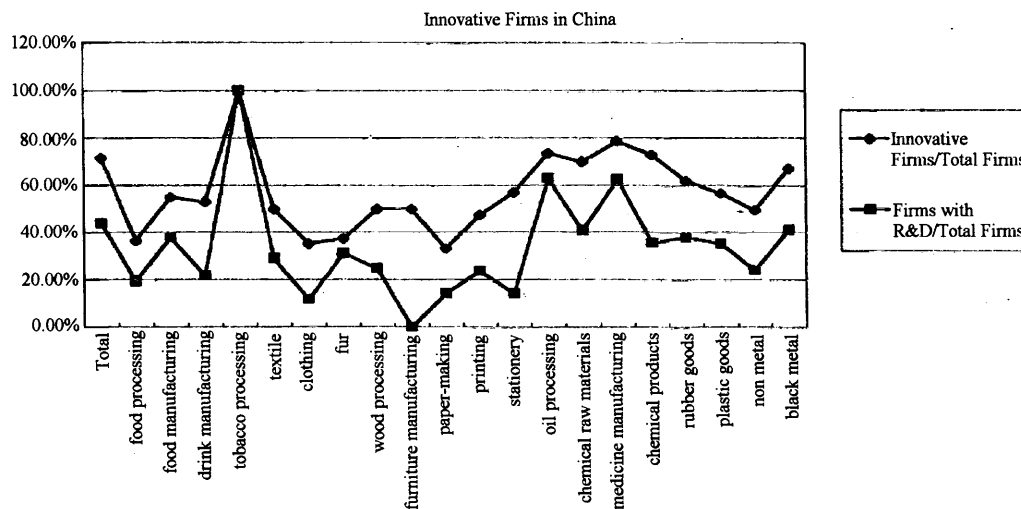


Fig. 1 Industrial Difference on the Innovation Level

The inputs into the technological innovation are the prerequisites for the successful innovations, and attention should be paid by S&T policy. Here, the inputs of technological innovation are production equipment, human resource and innovation capital.

Our data show that few enterprises own equipment at the international level (lower than 5%), 43.66% of the equipment at these firms are at the national advanced level. So poor equipment level is a problem faced these enterprises, especially in the clothing, textile and printing industry, around 33%—50% of the firms use poor equipment (See Fig. 2).

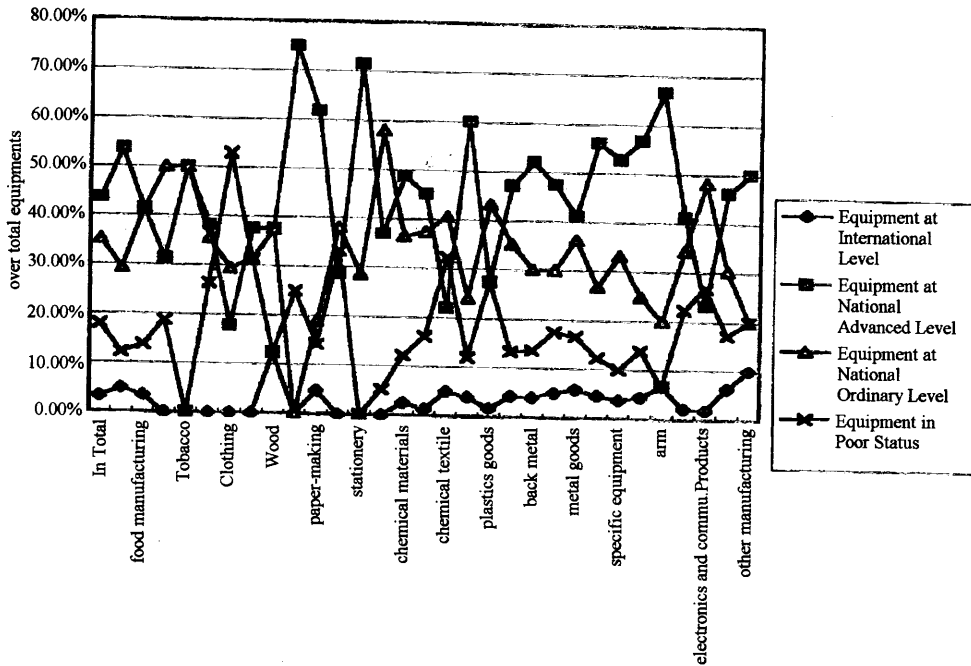


Fig. 2 The Equipment Level in Chinese Firms

The technical persons, especially the core professionals of high quality, are the core of technological innovation. Our data show that the ratio of technical persons over total employees is just around 10%, the highest ratio is 15.60%. Among the technical persons, 66.20% of them obtain college training.

The capital for innovation comes from enterprises themselves (self-raising), government support and bank loans. Since the economic reform, self-raising and bank loans are the main sources of innovation. Except the leather industry, fur and arm manufacturing, the ratio of government funds is low. Another phenomenon is that foreign capital is not the dominant source of innovation capital, almost half of the firms have no such item.

For the ratio of product innovation and process innovation, some of the industries are process innovation focused (in wood processing, printing, oil processing, nonmetal, heavy metal and transportation equipment manufacturing industry). In the tobacco, clothing and stationery industries,

the product innovation is dominant. In general, product innovation is paid more attention than that of process innovation.

Referring to the means of technological innovation, 46.84% of innovation is indigenous or self developed, while 53.16% is technology acquisition based. In the cloth and leather industries, 80% of the products rely on foreign technology, and in the industry of drink, tobacco, wood processing and stationery industries, 70%—80% of the products is self-developed.

Among the indigenous innovations, the ratio of independent R&D is 65.22%, cooperative R&D is 26.40%, contracted R&D is 8.38%. As a result, many enterprises prefer cooperative R&D to contracted project.

As to technology acquisition, 56.95% are domestic and 43.05% come from abroad. But if we comprehensively consider the cooperative R&D with foreign institutes, technology acquisition based development and production, international R&D is the vital means of technological innovation for these Chinese firms.

Referring to the cost structure of innovation, 54.66% of it is used for the purchasing of machine and equipment, and R&D cost is only 13.56% (See Fig. 3). That means the large and medium enterprises still focus on hardware instead of software.

It should be noticed that training expenditures are relatively low in every industry, and only accounts for 2%—3%.

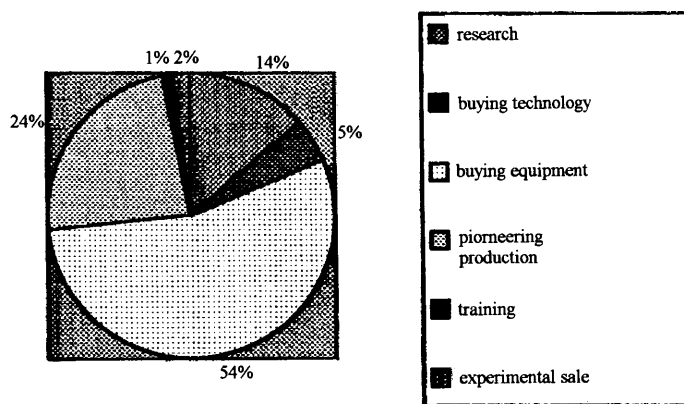


Fig. 3 Average cost distribution of technological innovation

As the novelty of innovation, the average industry level is 33.64%, and wood processing, furniture, chemical fiber, nonmetal, black metal, arm, electric and electronics telecommunication equipment are among the higher ones in innovation level. There is less innovation with novelty at the international level, only 14.37% of the metal manufacturer reach the international ones.

The new production yield over sales is 22.77% on average, some data are as follows: mechanical manufacturing (31.98%), electric products (31.12%), electronics and telecommunication (49.39%). These data show that the higher technology and high value-added products contribute more to corporate profit.

III. INNOVATION IN DIFFERENT ECONOMIC TYPE

As shown in Table 1, the productivity, profitability and profit per capita of joint ventures are highest, which explains their stronger competitive advantage. The heavy burden of state-owned firms impairs much of their competitiveness.

Table 1 The introduction of technological innovation

	Productivity (Yuan per capita)	Funds profit margin (%)	Owes / Assets (%)	Sale profit margin (%)	Profit per capita (Yuan)	New product prop. (%)	New product sale / Total (%)	New product profit / Total (%)
Total	33000	4.21	66.13	5.31	7000	33.64	22.77	26.30
State-owned	24000	2.66	62.84	3.88	4000	29.96	15.57	18.08
Joint-stock	50000	7.63	55.70	8.72	15000	53.47	30.66	22.35
Joint venture	93000	8.27	62.81	7.46	27000	35.40	36.36	39.82
Others	35000	5.03	110.79	5.07	6000	36.31	27.07	33.11

The performance of the innovation in joint ventures, joint-stock corporations and other economies are better than that of state-owned firms. As to the proportion of innovative products to total products, state-owned firms, joint ventures, joint-stock corporations and other economies are respectively 29.96%, 35.40%, 53.47% and 36.31%. The ratios of new products sale and profit to the total in joint ventures are highest, while state-owned firms have the lowest values.

Joint venture industries have the biggest value (13.67%) of the ratio of international new products to the total, which accounts for 23.33% of the total sales. The values for state-owned firms are respectively 4.37% and 9.53%. This makes clear that joint ventures think highly of technological innovation and attach much importance to develop high value-added products with international competitiveness. Though state-owned firms are not capable at this respect, they have advantages in the domestic market, for their national new products. The higher the novelty degree of product, the bigger the proportion of its sale income to the total by comparison to the sale quantity, Figure 4 which suggests amplification effect. Thus the firms should strive to develop advanced innovative products.

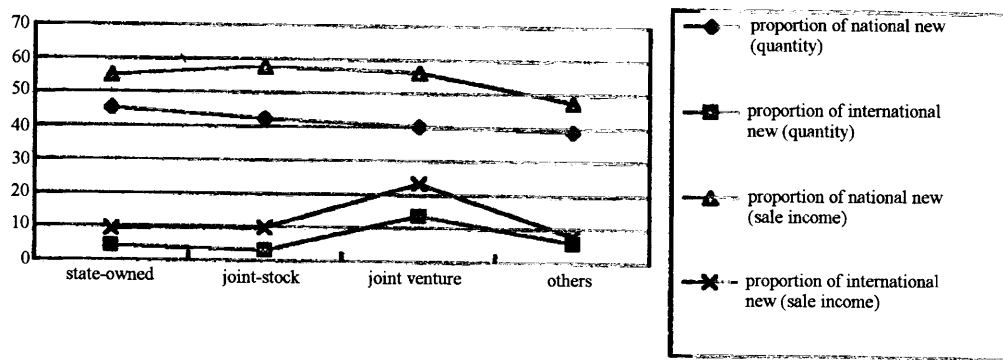


Fig. 4 The Novelty of Innovation in different firms

Figure 5 illustrates the distribution of the costs in innovation activities. State-owned firms and joint-stock corporations have higher research cost (18.57% and 18.60%) and lower external technology purchasing cost (4.72% and 5.54%). On the contrary, the two values for joint ventures are 7.35% and 6.61%. Others types have the highest proportion of equipment purchasing cost, but are lowest in the other respects.

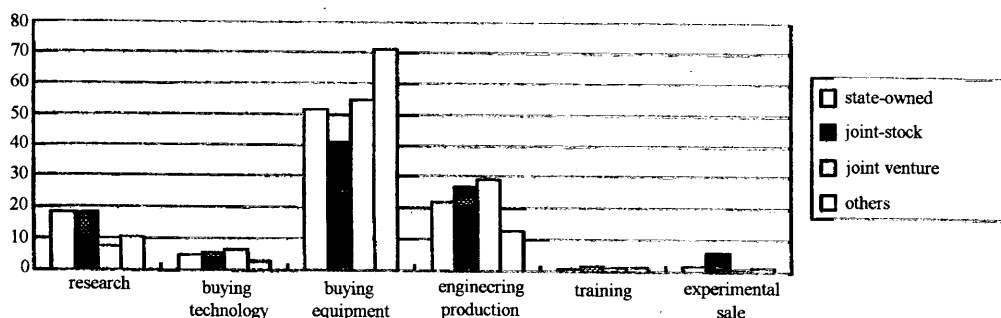


Fig. 5 Costs distribution of technological innovation in different firms

Concerning the mode of technological innovation, independent innovation take the lead in state-owned firms (50.00%) and joint-stock corporations (59.33%), in which the proportion of independent research account for 72.20% and 74.20% respectively, as shown in Fig. 6. Joint ventures

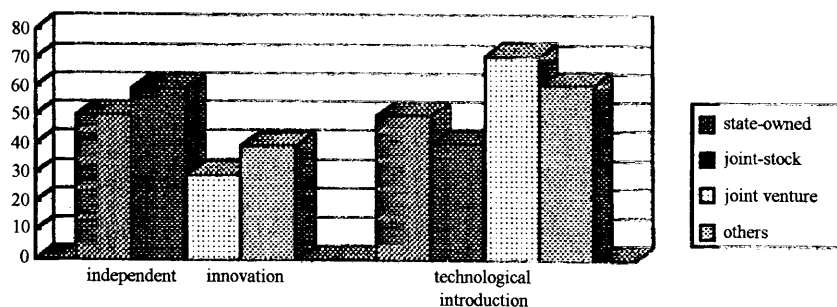


Fig. 6 Different modes of technological innovation in different firms

and others pay more attention to technological introduction, 70.83% and 60.60% each. On introducing technology, joint ventures develop 53.93%, launches 74.08%, collaborative researches 47.31%, as shown in Fig. 7. All the values are higher than those of the others. Joint ventures also collaborate more with foreign agents. It makes clear that joint ventures prefer introduction and collaboration.

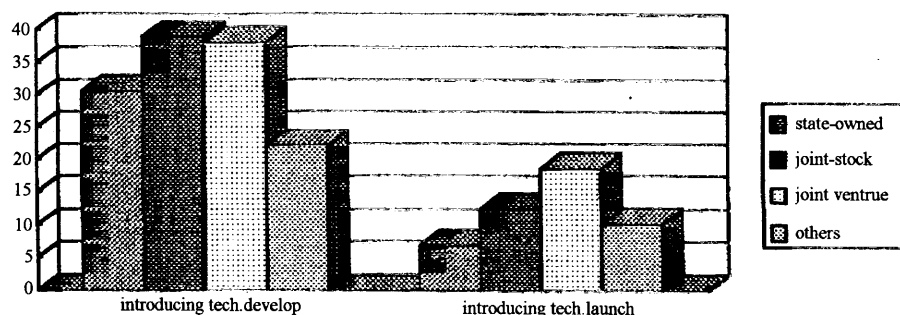


Fig. 7 Proportions of foreign technology introduction in different firms

Other types firms have the highest proportions in national collaboration (33.57%) and research contract (29.60%), as shown in Fig. 8. This demonstrates the tendency of the innovation mode of these firms.

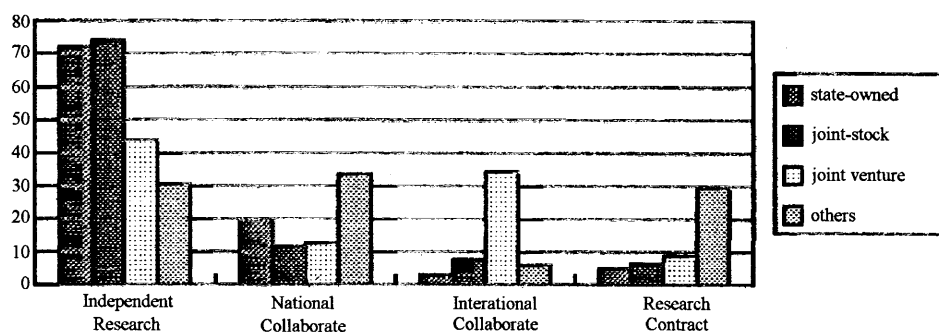


Fig. 8 Different modes of independent innovation in different firms

In the contents of innovation, all types of firms focus on product innovation, the ratio between product innovation and process innovation is 7:3.

Table 2 Contents of technological innovation in different firms

	Innovations	Product innovation			Process innovation	
		B	B/A(%)	B/T(%)	C	C/A(%)
Total	26195	17706	67.59	22.74	8488	32.40
State-owned	15028	10255	68.24	20.44	4773	31.76
Joint-Stock	3757	2687	71.52	38.24	1070	28.48
Joint venture	3826	2324	60.74	21.50	1501	39.23
Others	3584	2440	68.08	24.72	1144	31.92

IV. INNOVATION WITH THE SUPPORT OF R&D INSTITUTE

As Table 3 shows, enterprises which owns R&D institutes have better performance (both in the index of economic development and innovation level) than the enterprises with no established R&D institute.

Table 3 Comparison of Enterprises have/not have R&D Institutes

	Industrial Value Added (%)	Labor productivity (1000 yuan/man)	Profit over capital (%)	Profit/Sales (%)	Profit Ratio per capita (1000 yuan/man)	New Product (%)
Total	24.20	33	4.21	5.31	7	33.64
Without R&D Institute	20.30	28	1.27	2.74	3	21.03
Having R&D Institute	24.92	34	5.06	5.70	8	36.38

With Table 4, we see that enterprises which own R&D institutes have higher novelty in innovation.

Table 4 Novelty of Innovation with/without R&D Institute

Innovation Products	Novelty at National Level		Novelty at International Level	
	Numbers	Ratio(%)	Numbers	Ratio(%)
Total	11352	43.34	1519	5.80
No R&D Institute	1242	42.51	114	3.90
Owens R&D Institutes	10110	43.44	1405	6.04

By analyzing the cost structure of innovation, we see that the enterprises which own R&D institutes have higher input on R&D, engineering and pre-production, while the enterprises without R&D institutes spend more on machine and equipment (See Fig. 9).

As the novelty of new product, 6.04% of the enterprises which own R&D institutes reach the international level, for those enterprises with no R&D institutes, the ratio is just 3.90%.

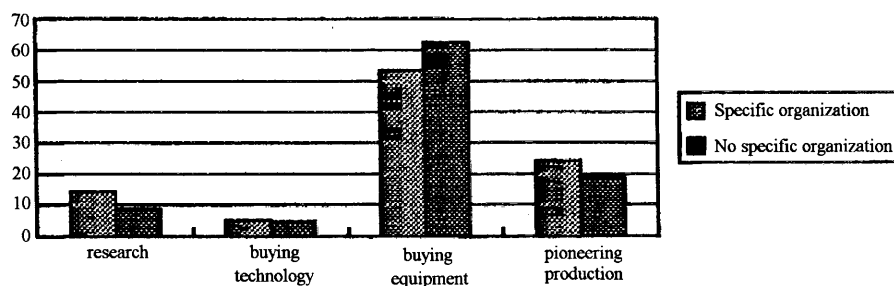


Fig. 9 Costs distribution of technological innovation

V. DISCUSSION

By studying of innovation activities in different industries, and economic system/types, the following conclusion can be drawn:

1. Government's Support is Important to Technological Innovation in a Firm

There are three kinds of support to technological innovations in firms, the first is financial aids, the second is scientific and technologic programs of government, the last is government policies.

In terms of technological innovation projects, 29.1% of the total 26,195 projects in 1993—1995 got financial aids from the government. According to project statistic, of all the projects, 4.5% get appropriated funds from the government, 10.2% get appropriated loans, 10.0% get tax shelter, 11.1% get other direct financial aids.

Financial aids are a major way to promote technological innovations in firms. In terms of expenditure, appropriate funds and loans account for 21.7% of the total expenditure in technological innovations in firms. Among them, appropriated funds account for 2.3%, which are mainly invested in state-owned enterprises and stock companies; appropriated loans account for 19.4%, which supports a wide range of firms (Table 5). In state-owned enterprises, collective-owned enterprise, Sino-foreign cooperation enterprises, and Hongkong-Macao-Taiwan-mainland cooperation enterprises, the rate of appropriated loans are above the average.

Table 5 The distribution of government financial aids in terms of firm type

Firm type	Total expenditure in Tech. Inno.	Appropriate funds	Appropriate loans
State-owned enterprises	100.0	4.8	27.1
Collective-owned enterprises	100.0	0.4	21.7
Private enterprises	100.0	0.0	0.0
Joint-operation enterprises	100.0	0.8	12.7
Stock companies	100.0	2.4	14.9
Sino-foreign joint ventures	100.0	0.1	6.6
Sino-foreign cooperation enterprises	100.0	0.0	41.3
Foreign ventures	100.0	0.0	0.0
Hong KongMacao-Taiwan-mainland			
Joint ventures	100.0	0.0	11.7
Hong Kong-Macao-Taiwan-mainland			
Cooperation enterprises	100.0	0.0	41.4
Hong Kong -Macao-Taiwan ventures	100.0	0.0	0.0
Others	100.0	0.0	1.3
Total	100.0	2.3	19.4

The scientific and technologic programs directly promoted the technologic innovation in firms. This investigation shows that 51.0% of the “major technological innovation” realized by the large and middle size firms in 1993–1995 are listed in the different government scientific and technological programs. 47.2% of these “major technologic innovation” projects is listed in different national scientific and technologic programs. Among of them, 11.2% is listed in the national “torch program”, 7.4% in the national key S&T program and national technology development program respectively (see Table 6).

Table 6 The importance of government policies

Policy	Score in importance
Tax shelter	4.21
Appropriate loans in S&T development	4.07
Reward for S&T workers	3.96
Protection for intellectual property	3.75
Industrial policy	3.62

Favorable policy is an important ways to promote technologic innovation in firms. In the view of the firms, “tax shelter” and “appropriated loans in S&T development” are the most important favorable policies. “Reward for S&T workers” and “protection for the intellectual property” are also very important.

2. The Firm's Own Technological Capabilities is the Base of Technologic Innovation

The firm's own technological capabilities are very important to the opportunity identification, and success of the innovation. Technological innovation capability is concerned with R&D, manufacturing, marketing and so on. Some major factors will be discussed here.

Engineers and technicians. Engineers and technicians directly take part in R&D, management and marketing activities. So the level of technological innovations depends on the quantity and quality of them. According to the statistic analysis, the higher the ratio of R&D employees in firms, the higher the ratio of new product sales in the total revenue (See Table 7).

Table 7 The ratio of engineers & technicians and technologic innovation

The ratio of engineers & technicians(x)	The ratio of innovative firms(%)	The ratio of new product sales in total revenue(%)
$0 < x \leq 5\%$	55.6	22.0
$5\% < x \leq 10\%$	74.0	21.3
$10\% < x \leq 15\%$	82.1	26.8
$x > 15\%$	87.8	30.6

R&D organizations. “R&D department” is the major internal source of innovative ideas. It is more important than the external research units in the generation of innovative ideas. The firms with

R&D department emphasize developing new products more and have more indigenous innovation capabilities.

Production equipment. The production equipment is the most important part of the technological innovation infrastructure. This investigation shows that there is much variation across different industries. The equipment of more than a half of the firms in food, rubber manufacturing, non-ferrous metal refining, ordinary machinery, and special mechanic equipment industries are at the national leading level. But in some high technology industries such as electrical machinery and electronics and telecom equipment, the production equipment level is outdated. This maybe harm the competitive advantage of these industries.

So, setting up or perfecting the R&D institute is important for the technological innovation in the enterprises; in the meantime, the importance of R&D collaboration and cooperation with foreign institutes, focusing on the renewal of equipment for innovation should be stressed.

3. Increasing the Investment of the Technological Innovation and Optimizing the Investment Structure

It is found that the shortage of technology innovation funds is one of the key factors, which has inhibited the firms' technological innovation.

Effective innovation needs high input. Many entrepreneurs hope that the government would increase the input for technology innovation. But this is impossible in the condition of the market economy. We suggest that it would be important for firms to increase the technology innovation fund. Besides the self-capital accumulation, firms should enlarge the channels to raise money.

On the other hand, it is necessary for firms to optimize the investment structure for innovation. The main existing problem is that firms have expended more money on hardware facilities. It is necessary to think much more of investment in the development of the up-stream technology and software technology. Government should lead firms to increase the input in research and development, and improve their technology independence. It needs further explanation that improving technology independence doesn't mean to refuse the acquisition of the foreign advanced technologies. Acquiring foreign technologies will still be an important method for Chinese firms for a long time, but Chinese firms should improve the absorptive capability and decrease the dependence on the foreign technology. Therefore, we should acquire foreign technologies selectively, and provide appropriate R&D fund from firms and country.

In order to make full use of the technology innovation funds, government should establish and perfect the institution of the project evaluation. Especially, projects, for which government provides the funds and the funds are large, need pre-evaluation.

4. Developing an Entrepreneur Force which Dare to Innovate and Be Good at Innovating

Entrepreneurs are the decision-maker, organizer and directors of the firms' technology innovation. They play key roles in firms' technology innovation. Their personality characteristics and competence make a key influence on firms' technology innovation activities and the effectiveness. So, it is important for national economic development to train and develop a large number of entrepreneurs, who dare to innovate and are good at innovating. While appointing the firms' leaders, it should focus on the capability of "dare to innovate, be good at innovating". As the same, while evaluating the leaders' performance, it should focus on the evaluation of the performance in the decision making, organizing and directing for the technology innovation.

Because many firms' leaders are unfamiliar with the theories of technology innovation, it is necessary to diffuse the technology innovation knowledge through training. The contents of the training courses should include the primary theories, the common rules of the technology innovation, and the cases of technology innovation in the foreign and local firms. It can teach together with the firms' management training courses, or conduct short-term training courses independently.

VI. TOWARDS INNOVATION-ORIENTED S&T POLICY

Up to now, China has gained marvelous achievements in technological innovation. For the better competitive advantage, innovation should be included more in the contents of S&T policy. By our research, some inspirations for S&T policy are given as below:

(1) Providing specific innovation guidelines

According to our new findings on the innovation differences in industry, according to economic system, some general and universal guidelines for the firms are insufficient. Instead, some concrete and specific guidelines should be given for the effective innovation in the firms. For example, the state enterprises should stress not only innovation in technology systems but also institutional and cultural innovation to keep abreast of or catch up with joint ventures, stock system firms and the collective ones. The enterprises in different industries should adopt different input ratio for R&D and equipment renewal.

(2) Providing more incentive for more innovation input in the enterprises

More input on technological innovation should be provided by the firm itself, and national S&T policy could offer more incentive for it.

Technological innovation funds are scarce and should be used for the development of big innovation projects. The government's main function is to create good conditions for firms to raise innovation money and to make it possible for firms to raise money in the capital market. For example, it is necessary to establish venture capital market and bank credit support to help the firm to get more

money for innovation projects.

In order to improve the firm's technology competence, it not only needs to increase financial R&D investments, but also needs to enhance the R&D professionals force and improve R&D facilities. Government should adjust the deployment of the technical force, integrate part of R&D forces of the government research institutes to the firms to formulate the corporate-dominant technology development system. Government should encourage and facilitate the integration of production, science and development, encourage the alliance between excellent firms to establish research and development organizations. As the owner of the capital, government should select some key state-owned corporate and company limited, provide the development funds, improve their facilities, and help them establish R&D organizations. The firms should also improve the technology competence by themselves, especially focusing on the establishment of technology development organizations.

(3) Enhance the “linkage” among the innovation chains

The essence of technological innovation is to link science, technology, production and marketing. As the linkage of production and marketing will be gradually improved by the firms themselves, the government should pay more attention to the external linkage: sources of technology. Thus S&T policy should support international cooperation in technological innovation, including inviting more technology-based MNCs to set up research institutes or joint ventures, rapid construction of the INTERNET, more international S&T forums and conferences, and collaboration.

Information Requirements for the Knowledge-based Economy

Commentary

William A. BLANPIED*

Isn't it a pleasure to make practical use of the things you have studied? Isn't it a pleasure to have an old friend visit from afar?

Kung Fu-tzu (Confucius)

The title of the first plenary session of the Sino-US Science Policy Seminar was, "Information Requirements for the Knowledge-based Economy." An implicit subtitle might have been, "Information Requirements for International Scientific Cooperation." That would have been eminently appropriate, in view of the global character of the knowledge-based economy.

A central rationale for the seminar was to provide an occasion for information exchange between the Chinese and U. S. participants from several types of organizations about:

- their current science policy-related interests and concerns, separate as well as shared;
- the principal challenges each side perceives both in advancing their separate national science policy interests and in seeking areas for closer cooperation; and
- their perceived future science policy goals and directions.

FENG Xuan's stimulating paper entitled, "Technological Innovation: Analysis and Implication for Chinese S & T Policy", presented during the first session, dealt with all three points. For example, the status of technological innovation in China and the factors underlying successful innovation are of considerable interest to the country's political and scientific leadership. Adequate information, such as FENG's paper reviewed in quantitative detail, will clearly remain essential in formulating policies to promote successful innovation. It is equally clear that the promotion of technological innovation will remain an important future goal for the country. FENG's paper was also important in providing the US participants with insights not only into the technological innovation process in China, but also about the current state of knowledge about the innovation process itself. The avail-

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ability of such information is an essential prerequisite to productive bilateral cooperation either to understand the innovation process in more detail, or in formulating policies to facilitate innovation.

David HART's paper entitled, "Context for International R&D Cooperation," provided a context for much of the discussion during the ensuing sessions of the seminar. He emphasized that whereas almost by definition all seminar participants favored increased international scientific cooperation, such cooperation should not be undertaken simply for its own sake. Rather, realistic priorities based on shared goals are an essential prerequisite to productive cooperation, whether international or otherwise. Adequate information about the interests of and resources available to potential international partners constitutes a minimal requirement for identifying such mutually beneficial goals and for establishing realistic priorities.

Various categories of international scientific cooperation were referred to during the two days of the seminar. These included: cooperation in planning, constructing and operating large and expensive research facilities, such as particle accelerators, or optical and radio telescopes. They also included major distributed projects undertaken on a worldwide basis, such as genome mapping and sequencing and global change research. As with all effective research cooperation, the scientific communities of cooperating countries must take the initiative for conceptualizing and advancing such projects. However, because of the cost and complexity of such projects, whether in the fixed facility or distributed category, experience demonstrates that governments must also be involved in planning from an early stage.

Despite the prominence of large-scale cooperative research projects, the majority of international research cooperation involves cooperation between individual scientists or small groups from two or more countries, together with their graduate students and postdoctoral scholars. In these cases the role of governments should be limited to encouraging and facilitating the cooperative efforts of the researchers.

Two other important although often-neglected categories of international cooperation referred to repeatedly during the seminar also deserve emphasis. The first category involves exchange of information which, of course, occurred throughout the seminar. There was a broad consensus among participants that information exchange on critical science policy issues between appropriate Chinese and U.S. experts needs to be pursued in a more focused, detailed manner.

The second closely related category involves cooperation in developing and refining internationally comparable statistical tools to understand better trends in important national and international aspects of the scientific enterprise. FENG's paper presented in the first plenary session provided one good example. Others emerged during the breakout session on Data Requirements for Policy Making and R&D.

Both of these types latter types of cooperation i. e. , information exchange and methodological coop-

eration-need to be initiated and pursued by working scientists. However, neither can proceed without the active encouragement and support of governments.

HART's paper identified several barriers to international research cooperation, among them: ignorance of the interests and resources of potential partners. The Beijing seminar constituted a useful start in exchanging the types of information that can lead to more extensive and effective cooperation. But the work begun in Beijing needs to be expanded to include many other individual participants and organizations in both China and the United States, and also deepened to encompass more detail.

HART's analysis made a useful distinction between barriers to international cooperation at the scientist-to-scientist level, and barriers at the governance level—that is, among institutions that encourage and support (or deny support) for international cooperation. HART's paper also suggested a simple, if idealistic goal for the decade-long series of science policy dialogues that China and the United States plan to organize: namely, to develop a lively international civil R&D society.

In the United States, the term "civil society" connotes a private, non-official grouping of individuals with common aims who join together to further their objectives. HART's formulation, therefore, envisions a future in which scientists in both China and the United States (and other countries as well) can enjoy a lively, open, and productive interchange of views leading to useful and mutually beneficial research cooperation. But of course no such international society of working scientists can exist and prosper without the active support and encouragement of governments. Perhaps the principal challenges that emerged from the two days of discussion at Beijing were how to reduce barriers to international cooperation at both the level of the working scientists and governments, and how to achieve an appropriate balance between the roles of individual scientists and their institutions, and the roles of governments, in furthering appropriate and productive cooperation.

It is worth noting that the English word "policy" is derived from the same Greek root as "polis", designating the City. During the third century before the current era, Athenian philosophers and politicians spent a great deal of time debating the attributes of the ideal city, which they regarded as a microcosm of the ideal civil society. But of course they were already three centuries too late to have much claim to originality. For during the sixth century before the current era, the scholar Kung Fu-tzu, known in the West as Confucius, was already teaching his countrymen the attributes of a just civil society.

Although the principal concern of the October 1999 Science Policy Seminar in Beijing was how to expand and make more effective scientific cooperation between the China and the United States in the 21st century, perhaps we were really asking how the teachings of Fu-tzu and the Greek philosophers who also dealt with attributes of the ideal civil society three centuries later could be adapted to our current circumstances.

*Americans of all ages, all conditions, and all dispositions, constantly form associations. . .
Wherever, at the head of some new undertaking, you see the government in France, in the
United States you will be sure to find an association.*

Alexander de Tocqueville

Parallel Breakout Session, Part I: Information Requirements for Policy-making

Using National Accounts to Assess the Role of R & D in the U. S. Economy¹⁾

Barbara M. FRAUMENI and SUMIYE Okubo *

Abstract The importance of R&D in stimulating economic growth has long been recognized. R&D by individuals, firms, nonprofit institutions, and governments leads to innovation, which in turn leads to economic growth. Although the existence of a link between R&D, innovation, and economic growth is widely acknowledged, it is difficult to quantify this link as R&D output, a critical component of the link, is not easily measured. Accordingly, R&D input measures such as R&D expenditures or R&D employment are frequently used as a gauge of R&D output. In addition, the existence of both direct and indirect (spillover) effects from R&D increase the measurement challenge.

The pharmaceutical industry is an example of a R&D intensive industry. The distribution of benefits from R&D may be widespread and unclear. In the pharmaceutical industry drugs may be jointly developed, leading to joint direct benefits, and discoveries may result in other discoveries, leading to spillovers. Some R&D may be supported and even performed by nonprofit institutions and government. With nonprofit institutions and government it is frequently less clear who benefits than it is with private business. The benefits from any discovery may have an impact on both businesses and consumers in the present and in the future. The discoverer may not fully capture the rewards to R&D as royalties and sales revenue may be less than the value of the discovery to third parties. In particular, there may be no payments reflecting the impact of a discovery on future discoveries.

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1) This paper represents views of the authors and is not an official position of the Bureau of Economic Analysis or the Department of Commerce.

This paper outlines a general measurement framework which could be used to assess the effect of R&D on economic growth. The core of this framework is a satellite account.²⁾ The R&D satellite account (R&DSA) could be used to trace the direct effect of R&D. Satellite accounts are rearrangements of information from the national economic accounts and other sources for the purpose of analyzing specific economic activities more completely than is possible within the structure of the basic accounts. The R&DSA would use an input-output (I-O) framework. It would treat R&D as investment and would substantially extend earlier Bureau of Economic Analysis (BEA) work on a R&D satellite account. Performers' output of R&D would be defined as the value of performers' inputs to R&D. This output, redefined as investment, would be a net addition to gross domestic product (GDP). Accordingly R&D's direct impact on economic growth, through R&D investment's impact on GDP growth, could be measured.

The suggested general measurement framework also includes estimates of rates of return and improved measures of goods and services. Rates of return are important in capturing the indirect or spillover effect of R&D, which includes the return to R&D not fully captured by the performer of R&D. A full rate of return to R&D would be estimated. A full rate of return captures both the benefits to the entity undertaking the R&D, the direct return, and to others, the spillover return. The size of the spillover is indicated by the difference between an estimated direct rate of return and an estimated full rate of return. Although direct and spillover benefits may already be included in the national accounts, they are not separated from benefits from other types of economic activity. Rates of return on R&D capital allow the identification of these benefits. In addition, as rates of return are typically applied to R&D stocks, it is recognized that current R&D investment, from the satellite account, yields future returns.

Equally important to understanding the effect of R&D is the development of improved measures of new goods and services, including goods and services embodying technical innovations. These measures include estimates of intermediate inputs (such as semiconductors) and final expenditure goods (such as telecommunications switches, cell phones, and pharmaceuticals). Improved measures allow for a more accurate picture of the impact of R&D on the economy.

I . Definition of R&D

The Organisation for Economic Co-operation and Development (OECD) in the Frascati Manual defines R&D as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowl-

2) See Carol S. Carson, Bruce T. Grimm, and Carol E. Moylan, "A Satellite Account for Research and Development," Survey of Current Business, November 1994.

3) Organisation for Economic Co-operation and Development (OECD), Frascati Manual 1993: The Measurement of Scientific and Technological Activities: Proposed Standard Practice for Surveys of Research and Experimental Development, Paris, OECD, 1994.

edge to devise new applications."³⁾ R&D is also characterized as the sum of three types of activities—basic research, applied research, and development.

R&D is to be distinguished from a wide range of related activities that are linked to R&D both through flows of information and in terms of operations, institutions, and personnel.

II. Review of Alternative Approaches to Analyzing the Role of R&D

Several alternative approaches have been used to analyze the role of R&D in the U. S. economy. Each of the approaches includes measures of R&D inputs. One approach uses the growth in R&D inputs as indirect measures of technical advance, and economic and productivity growth as proxy measures for the results of R&D. A second approach uses growth accounting models in combination with regression and statistical analysis to determine the role of R&D in enhancing economic growth.

Proxy Measures of R&D Output

Proxy measures of the contribution of R&D to economic growth include growth in R&D spending, the ratios of R&D to GDP, R&D personnel, stocks of R&D, patent counts, capital-to-labor ratios, and technology balances. These data show which firms, industries, or countries are devoting the most and growing resources to the R&D effort, and which are producing and selling the most technology, as reflected in patent data and the technology balances.

The impact of R&D on the U. S. economy is often assessed using measures of economic growth or productivity growth. These measures include growth in real GDP, GDP per capita, and GDP per worker. Growth in real GDP reflects the result of innovation as incorporated in new goods and services, improved production processes, and/or quality changes in existing goods and services, as well as a number of other factors. Growth in GDP per capita and GDP per worker are used as normalized measures of economic growth or productivity growth. However, these measures do not show the extent of the contribution of R&D to growth.

Analysis Using Growth Accounting Models

Regression and statistical analyses provide a means to examine the role of R&D in promoting economic growth. These approaches typically use growth accounting models to analyze the relationship between output and inputs to production to determine the contribution of inputs, including R&D.⁴⁾ They are part of a rich tradition examining the sources of economic growth, including productivity growth, as epitomized by the work of Edward F. Denison, John W. Kendrick, and more

4) See Robert M. Solow, "Technological Progress and the Aggregate Production Function," Review of Economics and Statistics, 39, August 1957, pp. 312—320; and Dale W. Jorgenson, "Technology and Growth Theory," presented at the Federal Reserve Bank of Boston Economic Conference on Technology and Growth, Chatham, MA, June 5—7, 1996.

5) See Edward F. Denison, Trends in American Economic Growth, 1929—1982, Brookings Institution, Washington, DC, 1985; John W. Kendrick, Postwar Productivity Trends in the United States, 1948—1969, National Bureau of Economic Research, Number 98, General Series, New York, NY, 1973; and Dale Jorgenson, Frank Gollop, and Barbara Fraumeni, Productivity and U. S. Economic Growth, Harvard University Press, Cambridge, MA, 1987.

recently by Dale W. Jorgenson and his co-authors Frank M. Gollop and Barbara M. FRAUMENI.⁵⁾ R&D expenditures have been listed as a possible cause of productivity growth in the attempts to identify the factors behind the so-called Solow residual.⁶⁾

The basic growth accounting model starts with a production function which specifies output as a function of inputs and productivity change.⁷⁾ Intermediate input is usually determined from the information in an I-O matrix. Capital input is sometimes measured by capital stock rather than by capital input (capital services).⁸⁾ Labor input is sometimes measured by employees or hours worked rather than labor input (labor services). R&D input is frequently measured by an index of R&D expenditures or R&D stock, and sometimes by the number of employees involved in R&D or the average age of tangible capital under the assumption of technology being embodied in capital,⁹⁾ rather than R&D input (R&D services). Estimates of a rate of return to R&D stock and depreciation are required to measure R&D input. Therefore, direct measures of R&D input are used less frequently than direct measures of intermediate, capital, or labor input.

Two types of effects of R&D on economic growth have been examined the direct effect and the indirect effect. The direct effect is the benefit from R&D derived by the firms and industries actually undertaking the research and development; the indirect effect is the benefit from R&D undertaken by others, e. g. , the use of higher quality or new inputs developed through R&D and benefits from technology transfers.¹⁰⁾ Innovation can also result in new and improved consumer goods and services. These latter effects, often called spillovers,¹¹⁾ have benefitted firms and consumers buying these goods and services. Taken together, these two effects could be very large.

III. General Measurement Framework

The suggested framework for measuring the role of R&D has three essential components a satellite

6) See Edward F. Denison, Accounting for Slower Economic Growth, the United States in the 1970's, Brookings Institution, Washington, DC, 1979, pp. 122–127; and John W. Kendrick and Elliot S. Grossman, Productivity in the United States, Trends and Cycles, The John Hopkins University Press, Baltimore, MD, 1980, pp. 10, 16–18, and Chapter 6, pp. 100–111.

7) See Bureau of Labor Statistics, U. S. Department of Labor, The Impact of Research and Development on Productivity Growth, Bulletin 2331, September 1989; and National Science Board, Science and Engineering Indicators, 1996, National Science Foundation, Washington, D. C. , 1996, Chapter 8.

8) The factor input (services) is a measure of the flow of productive input from the factor. When inputs are aggregated over heterogeneous factors, such as different types of capital, the services are weighted by the income received by the factor. This weighting under certain assumptions reflects the relative marginal products of the heterogeneous factors.

9) Jorgenson (op. cit. , 1996) has argued that many technical changes are embodied in capital goods.

10) See Bureau of Labor Statistics (1989), op. cit. , p. 5.

11) Griliches distinguishes between two types of spillovers. One is the spillover from purchasing the results of R&D inputs at less than their full quality price. This spillover reflects a problem of measuring improvements in the quality of capital and materials and their prices correctly. The second type are knowledge spillovers, and refers to ideas borrowed by research teams in one industry from the research results from another industry. See pp. 65–66 of Zvi Griliches, "R&D and Productivity: Econometric Results and Measurement Issues," in Handbook of the Economics of Innovation and Technological Change (Cambridge, MA; Blackwell, 1995), pp. 52–89.

account, estimates of full rates of return, and improved measures of new goods and services. The satellite account reclassifies R&D expenditures as investment, as part of an I-O sources and uses account. Industry, nonprofit institutions, and government perform R&D. R&D is either own-account (in-house) R&D or for-hire R&D. Calculation of full rates of return as suggested requires R&D stock accounts,¹²⁾ such as those contained in BEA's earlier satellite account, as well as identification of the "spillover" rate of return. Improved goods and services measures are critical to understanding how the benefits from R&D flow through the economy.

R&D Satellite Account

BEA has a long tradition of constructing satellite accounts.¹³⁾ The System of National Accounts 1993, a blueprint for national accounts around the world, includes a chapter on satellite accounts, with an R&D account as one of the featured examples.¹⁴⁾

The R&DSA outlined in this paper has an I-O account at its core. Commodity flows will be shown with R&D separately identified. R&D will be classified as investment as opposed to being classified as private business intermediate expenditures or consumption by nonprofit institutions or government as is currently done. These changes necessitate several modifications to private business incomes and consumption of fixed capital (CFC) components of gross domestic income. In addition, treating R&D as investment necessitates changes in the handling of R&D expenditures by the private nonprofit and government sectors.

The idea of treating at least some components of R&D expenditures as investment is not new. What is new is the suggestion that R&D investment could be embodied in a complete and consistent set of accounts that could be used to analyze the contribution of R&D to economic growth.

The R&DSA identifies and aggregates across private business R&D activities by whether R&D is purchased from other firms, or performed by units within a firm, and presents the data on an industry and commodity basis. They define a new industry, R&D, which includes both purchased and own-account R&D activities, and a new commodity, R&D, which is produced by research establishments, laboratories, and own-account by firms, nonprofits and government.¹⁵⁾ The R&DSA takes advantage of the detailed information on R&D already included within an I-O account, and

12) See Carol S. Carson, Bruce T. Grimm, and Carol E. Moylan (1994), op. cit.

13) Simon Kuznets, a prime architect of the U. S. national accounts, originally envisioned several extensions of the accounts, particularly to facilitate international comparisons. See Simon Kuznets, National Income: A Summary of Findings, National Bureau of Economic Research, New York, N. Y. , 1946.

14) Commission of the European Communities, International Monetary Fund, Organization for Economic Co-operation and Development, United Nations, and the World Bank, System of National Accounts 1993, Brussels/Luxembourg, New York, Paris, Washington, DC, 1993, Chapter XXI.

15) Under the 1997 North American Industrial Classification System, captive research laboratories, which undertake in-house R&D and are separate establishments primarily involved in research, will be reclassified as commercial laboratories.

generally uses the concepts, definitions, and accounting practices used in an I-O account. Unlike an I-O account, the R&DSA identifies and estimates the inputs required by each industry, nonprofit or government agency for R&D, and separates inputs required for R&D from inputs required for the primary production activities. Inputs to the R&D industry are separated into purchased R&D and own-account R&D, and classified as an intermediate input, or a value added component (e. g. , compensation for scientists and engineers).

On the product side R&D would be recognized as fixed investment. This represents a departure from the conventional treatment in the national accounts.¹⁶⁾ Like assets currently included in fixed investment, R&D produces a flow of services that lasts more than one year. Private business purchases of R&D are added to fixed investment and thus to GDP. Currently, these purchases are treated as intermediate inputs; as a result, they are omitted from the calculation of GDP as the sum of final expenditures, and they are subtracted from gross output in the calculation of gross product by industry (value added). Private business own-account R&D production would also be added to fixed investment and thus to GDP. For the calculation of industry gross product, own-account R&D production would be redefined as part of gross output and thus would be added to the gross output and gross product of industries engaged in producing own-account R&D.¹⁷⁾

On the income side, treating R&D as investment also affects the private business income and CFC components of gross domestic income. Private business income (proprietors' income and corporate profits) would increase because purchases of R&D are no longer deducted as intermediate inputs and because the value of the production of own-account R&D is added as a receipt.

Treatment of R&D expenditures by private nonprofit institutions and by general government agencies follows the approach used in the earlier estimates produced by BEA.¹⁸⁾ This approach estimates the stock of R&D investments based on the performer of R&D, rather than the funder, in order to avoid having to make adjustments for timing between payment and performance and the possibility of double counting.¹⁹⁾ Nonprofit institutions and government purchases of R&D are subtracted from personal consumption expenditures (PCE) and government expenditures, respectively. These expenditures would be added to private business expenditures on R&D when private businesses are the

16) In the National Income and Product Account (NIPA) benchmark to be released on October 28, 1999 computer software is recognized as investment. Some of the software supports R&D activities or is non-routine software development; accordingly in the revised NIPA's some of R&D will already be categorized as investment. See Brent R. Moulton, Robert P. Parker and Eugene P. Seskin "A Preview of the 1999 Comprehensive Revision of the National Income and Product Accounts, Definitional and Classificational Changes," *Survey of Current Business*, August 1999, pp. 7-20. Also see the previous section on the definition of R&D.

17) This treatment is the same as that used by BEA for own-account, or "force-account," new construction and major improvements, which is currently recognized as investment in private and government structures in the NIPA's, and the same as the treatment of own-account (in-house) software production.

18) Carson, Grimm, and Moylan (1994), *op. cit.*

19) Carson, Grimm, and Moylan (1994), *ibid.*, p. 53.

performer of the R&D to derive private business R&D investment. When nonprofit institutions and government are performers, these expenditures are added to that of R&D investment for nonprofit institutions and government. The sum of the private business, nonprofit institution and government R&D investment gives total R&D investment.

The BEA I-O Accounts, which are in current dollars, currently identify some R&D inputs and final uses. The general types of R&D inputs identified are listed in Table 1; the general types of R&D final uses identified are listed in Table 2. The primary performers of R&D are commercial and non-commercial research entities, and educational institutions. On the input side, government and nonprofit institutions support of R&D performed by private business is included as an intermediate input to the production process of the performing private business.

Table 1 R&D Inputs in the BEA I-O Accounts

Private business R&D intermediate inputs
Commercial physical research
Colleges, universities, and professional schools (private)
Non-commercial research
Patent royalties
Other R&D inputs (as part of all other intermediate inputs)
R&D value added
Compensation of R&D workers (as part of compensation of all workers)
Other R&D value added (as part of other value added)
Total R&D input
Sum of R&D private business intermediate inputs and R&D value added

Table 3 illustrates the steps required on the input side to move from the current I-O accounts to those suggested for an illustrative commodity and industry. Step 1 identifies R&D expenditures for intermediate inputs by performers. In the example given, the performer is a private business without nonprofit institutions or government support for its R&D activities, so no entries are listed for R&D sponsored, but not performed, by nonprofit institutions or governments. The inputs from the for-hire R&D industry total \$ 11. Own-account R&D inputs, including value added, are included with inputs used to produce non-R&D output of the private business. Step 2 identifies own-account R&D. The inputs for own-account R&D production total \$ 9 (equals the sum of intermediate inputs (\$ 5), compensation (\$ 3), and other value added (\$ 1)). Once this is done, a new industry can be defined, the R&D industry, either as one industry including for-hire and own-account R&D as is done in Table 3 or as two industries, one a for-hire industry and the other an own-account industry. The output of the newly defined R&D industry, which is set equal to the value of inputs, is \$ 20 (equals the sum of intermediate inputs (\$ 16), compensation (\$ 3), and other value-added (\$ 1)).

Table 2 R&D Final Uses in the BEA I-O Accounts

R&D personal consumption expenditures
Nonprofit hospitals
Education and research
Higher education (including public colleges)
Other
Religious and welfare activities
R&D net exports of goods and services
Exports of services
Imports of services
R&D government consumption expenditures
Federal government
National defense
Contractual R&D
Other
Nondefense
State and Local government

Table 3 For-Hire and Own-account R&D in I-O Accounts for Industry X

Step 1: R&D Activities, Without Identifying own-account R&D

Commodity x	Industry x	Totals
Intermediate inputs		\$ 61
For-hire R&D	\$ 11	
Other inputs, including own-account R&D inputs	50	
Value added		39
Compensation, including compensation of own-account R&D workers	31	
Other value added, including own-account R&D other value added	8	
Total in dustry input (=output)	100	100

Step 2: Identifying own-account R&D Production in industry x

Commodity x	Own-account R&D Industry x	Totals
Intermediate inputs		\$ 5
Own-account R&D	\$ 5	
Value added		4
Compensation, own-account R&D workers	3	
Other value added, own-account R&D	1	
Total own-account R&D input (=output)	9	9

Step 3: Separating Out R&D Production from Non-R&D Production

Commodity x	Non-R&D Industry x	R&D Industry For-hire & Own-account	Totals
Intermediate inputs			\$ 61
Own-account R&D inputs		\$ 5	
For-hire R&D		11	
Other non-R&D inputs	\$ 45		
Value added			<u>39</u>
Compensation	28	3	
Other value added	<u>7</u>	<u>1</u>	
Total industry input (=output)	80	20	100

This output, which in the current BEA I-O accounts is treated as intermediate input, is in turn re-defined as investment. In the final use (GDP) account, investment increases by \$ 20. R&D output equals \$ 20 of which \$ 4 is already in GDP and value added. Accordingly, \$ 16 is the net addition to GDP and to value added.²⁰⁾ There are three components to the net addition to value added. First, private business profits (corporate profits or proprietors' income) increases because R&D expenses are no longer deducted from gross receipts. Second, some of the deductions for R&D expenses are offset by a deduction for CFC (depreciation), which in turn reduces private business profits by the amount of CFC's. Third, this reduction in private business profits is offset by an equal increase in CFC's, one of the other income components in other value added. Therefore, on net, total value added and other value added goes up by the amount of the output of the R&D industry less value added inputs to own-account R&D.²⁰⁾

Table 4 shows a general format for describing R&D activity in a satellite account. The table shows only row and column headings, R&D inputs, and R&D investment, to highlight the structure of the suggested R&DSA. The R&D industry, shown down the R&D industry column, uses commodities and value added to produce R&D output. The R&D commodity, shown along a row, is all delivered to a final use category, investment.

Rates of Return

Several researchers have attempted to estimate the rate of return to R&D. Case studies have looked at the impact of successful innovations, and provide estimates of the rates of return to R&D investments in these innovations. The studies have estimated high rates of return, ranging from 10 to 50 percent a year. However, the focus on successful innovations in agriculture and manufacturing limits any generalizations that can be made about the effect of all R&D investments on economic growth.²¹⁾ Econometric estimates of the effects of R&D spending by firms and industries show very high rates of return. Estimates of the direct returns to R&D average 30 percent per year, ranging from 20 to 40 percent per year. The indirect or spillover returns have been estimated at an average

20) As shown in step 2 of Table 1, value added inputs to R&D own-account production are \$ 4. As the current dollar sum of GDP must equal the sum of value added for the economy as a whole, the \$ 4 must be in GDP someplace.

21) See Zvi Griliches (1995), *op. cit.*, pp. 52-89, for a review of research approaches and findings.

Table 4 R&D Satellite Accounts Use of Commodities by Industry

Commodity	Industry				Final Uses			Totals
	Industry 1	Industry 2	Industry n	R&D In-house & For-hire *	Total intermediate use	PCE	Gross private fixed investment	
Commodity 1				C ₁				
Commodity 2				C ₂				
⋮				⋮				
Commodity 2				C _n				
R&D							R&D investment	
In-house For-hire								
Total intermediate inputs								
Value added								
Compensation								
R&D workers				R&D comp.				
Non-R&D workers								
Other value added * *								
R&D other VA				R&D other VA				
Non-R&D other VA								
Total industry output				R&D output				

* Government and nonprofit institutions, as performers of R&D are included in the own-account R&D industry, producing the commodity, own-account R&D. Government and nonprofit institutions expenditures for R&D performed by others are included in payments to the for-hire R&D industry.

* * Other value added consists of the following national income and product accounts components of gross domestic income: Proprietors' income with inventory valuation adjustment (IVA) and capital consumption adjustment (CCAdj), rental income of persons with CCAdj, corporate profits with IVA and CCAdj, net interest, business transfer payments, current surplus, current surplus of government enterprises less subsidies, consumption of fixed capital, and net payments of factor income to the rest of the world.

of 19 percent a year.²²⁾ However, at least one study of private returns to public R&D investment shows them to be zero.²³⁾

Under the approach suggested in this paper, R&D as an investment good is accumulated to form R&D stock. From that stock flows capital services, or capital input, into production. Capital service flows are composed of the return to capital and depreciation. The direct rate of return to capital can be estimated as the rate of return to capital times the stock of R&D for the performing business. The alternative method for deriving capital service flows from R&D is to associate private business profits and other capital income components of value added with R&D. The rate of return is then the capital service flow less depreciation divided by the stock.²⁴⁾ Most researchers will use the former approach as it is difficult to associate capital income components with R&D. The indirect rate, or spillover rate of return, would have to be determined as a function of the level of R&D stock of individuals, firms, nonprofit institutions, and governments.

The first step under the approach most likely to be used is to construct a R&D stock. R&D investment is included in the suggested satellite account. However, R&D lifetimes, patterns of R&D depreciation, and possibly a R&D stock benchmark are needed if the investments are to be converted to stocks using the perpetual inventory method. The direct benefits to the R&D performer are equal to the direct rate of return times the performer's R&D stock, plus depreciation. To determine the indirect or spillover benefits, a decision has to be made about which R&D stocks to include in the calculation: All R&D stocks in the economy, those specific to a related industry group, or some other aggregate stock. A judgment would then have to be made about the indirect rate of return that should be applied to the stocks before depreciation is added in to complete the calculation of the capital service flow from R&D. This indirect rate of return would likely be determined from the econometric studies noted above.

Under the perpetual inventory method, R&D end-of-year stock is equal to beginning of year capital stock plus gross investment minus depreciation. Depreciation is frequently defined by the average service life of an investment, a depreciation pattern, and a retirement distribution. However, if the R&D investment depreciates following a geometric pattern, only an average service life and a declining balance rate are needed.²⁵⁾

22) See Bureau of Labor Statistics (1989), *op. cit.*, pp. 12–14; Griliches (1995), *op. cit.*, pp. 56–63.

23) See Bronwyn H. Hall, "The Private and Social Returns to Research and Development," in *Technology, R&D, and the Economy*, edited by B. L. R. Smith and C. E. Barfield (Washington, D. C. : Brookings Institution and American Enterprise Institute, 1996), pp. 140–183.

24) In this discussion, for simplicity, revaluation is assumed to be zero and taxes are ignored.

25) Since the stock will be used for analyzing the contribution of R&D to economic growth, the production (productivity) concept of capital stock and capital service inputs (flows) are needed. For a discussion of the different concepts, see Jack E. Triplett, "Concepts of Capital for Production Accounts and for Wealth Accounts: The Implications for Statistical Programs", prepared for "The International Conference on Capital Stock", March 10–14, 1997, Canberra, Australia. For a discussion of how to construct a geometric depreciation rate, see Barbara M. FRAUMENI, "The Measurement of Depreciation in the U. S. National Income and Product Accounts," *Survey of Current Business* 77, July 1997, p. 11.

In the previous BEA R&DSA, the depreciation pattern was assumed to be straight line and the retirement pattern bell-shaped. The average service life for R&D investment was assumed to be 18 years, a number determined by taking an average yearly rate of depreciation of 0.11 percent per year. This rate was chosen because it was near the center of a plausible range of rates estimated by empirical studies.²⁶⁾ However, it should be emphasized that there continues to be a great deal of uncertainty regarding the appropriate depreciation assumptions.

The income generated from R&D performed by private entities already is included in any set of national accounts estimates. These estimates reflect a firm's higher profits because of its own innovation, as well as higher profits because of spillover effects. The problem is to separate out the income (measured benefits) generated from R&D from income generated from other activities.

There are also unmeasured benefits from R&D. Consumers may be receiving additional consumer surplus because of innovation embodied in commodities. However, consumer surplus, whether from innovation or other factors, is not reflected in national accounts estimates. The benefits from R&D performed by government would have to be imputed as no output is being sold. With respect to income generated from R&D, the problem is to determine the implicit income (measured benefits) arising from R&D. For governments, benefits could be imputed by applying a rate of return to government R&D stocks. For consumers, there is not an easy answer to the measurement problem.

Improved Measures

Improved measures of new goods and services, including goods and services embodying new technology, are critical to understanding the impact of R&D. These improved measures go hand-in-hand with a R&DSA as they can increase our understanding of how the benefits of R&D are transmitted through the economy.

As innovation frequently results in differentiated goods and services with improved qualities, quality-adjusted price indexes are key to the measurement effort. BEA has introduced a number of quality-adjusted prices into its accounts. These include quality-adjusted prices for computers, semiconductors, and telephone switching equipment.²⁷⁾ Our understanding of the contribution of computers

26) Carson, Grimm, and Moylan (1994), op. cit., p. 58.

27) See Cole, Rosanne, Y. C. Chen, Joan A. Barquin-Stolleman, Ellen Dulberger, Nurhan Helvacian, and James H. Hodge, "Quality-Adjusted Price Indexes for Computer Processors and Selected Peripheral Equipment," *Survey of Current Business*, January 1986, pp. 41–50; Bruce T. Grimm, "Price Indexes for Selected Semiconductors, 1974–1996," *Survey of Current Business*, February 1998, pp. 8–24; and Robert P. Parker and Eugene P. Seskin, "Annual Revision of the National Income and Product Accounts: Annual Estimates, 1993–1996; Quarterly Estimates, 1993:I–1997:I," *Survey of Current Business*, August 1997, pp. 6–35.

to economic growth has been significantly enhanced by the quality-adjusted price index, which has dropped significantly over time. This quality-adjusted price index, in combination with chain-type quantity and price indexes, better reflects the changing composition of GDP over time.²⁸⁾ Computer sales have accounted for between 13 to 17 percent of real GDP growth since 1994, in spite of only accounting for about 1 percent of current GDP over the same period.²⁸⁾

Three other technology-related improvements are incorporated into the NIPA benchmark estimates to be released October 28th. They are: changes in the treatment of software and unpriced banking services in the national accounts, and an upward revision in depreciation for personal computers. Private business, nonprofit institutions, and government purchases of software, as well as own-account production of software, will be recognized as fixed investment.²⁹⁾ Before this change, except for software embedded in equipment, private business and nonprofit institutions purchases and own-account production of software were classified as inputs to production, and government purchases and own-account production of software are classified as government consumption expenditures. Preliminary estimates of investment in software suggest that it is about \$ 115 billion or a little more than 1 percent of GDP in 1996. Using a bank output index published by BLS, real bank services will be recalculated. The new estimate of unpriced bank services will be a weighted average of various bank transactions, including ATM transactions, and volume of services. Introduction of the new banking measure will result in an upward revision to the rate of growth of real bank output and will affect several components of GDP, as well as the gross product of the banking industry.³⁰⁾ Personal computers had been depreciated using a depreciation schedule for all computers, excluding personal computers, and peripherals developed by Oliner.³¹⁾ The new depreciation schedule follows a geometric pattern and has a shorter service life than the implicit service life of the previous depreciation schedule.

BEA has also actively supported, along with the National Science Foundation, the research of

28) See J. Steven Landefeld, and Robert P. Parker, "Preview of the Comprehensive Revision of the National Income and Product Accounts: BEA's New Featured Measures of Output and Prices," *Survey of Current Business*, July 1995, pp. 31–38; and J. Steven Landefeld and Robert P. Parker, "BEA's Chain Indexes, Time Series, and Measures of Long-Term Economic Growth," *Survey of Current Business*, May 1997, pp. 58–68. Landefeld and Parker (1995, 1997).

29) Moulton, Parker and Seskin (1999), op. cit., pp. 7–20.

30) Brent R. Moulton and Eugene P. Seskin, "A Preview of the 1999 Comprehensive Revision of the National Income and Product Accounts, Statistical and Methodological Changes," *Survey of Current Business*, October 1999, forthcoming.

31) Stephen D. Oliner, "Estimates of Depreciation and Retirement for Computer Peripheral Equipment," Paper presented at the Workshop on the Measurement of Depreciation and Capital Stock at the Conference on Research in Income and Wealth, National Bureau of Economic Research, Washington, DC, June 5, 1992; Stephen D. Oliner, "Constant-Quality Price Change, Depreciation, and Retirement of Mainframe Computers," In *Price Measurements and Their Uses*, edited by Murray F. Foss, Marilyn E. Manser, and Allan H. Young, Chicago: University of Chicago Press, 1993, pp. 19–61; and Stephen D. Oliner, "Measuring Stocks of Computer Peripheral Equipment: Theory and Application," Washington DC: Board of Governors of the Federal Reserve System, May 1994.

Berndt and Griliches on measuring the contributions of new products to economic growth.³²⁾ This research emphasizes prescription drugs and personal computers and attempts to measure quality-adjusted prices of new products.³³⁾

IV. Conclusion

This paper suggests a possible framework for measuring the contribution of R&D to economic growth. At its core is a satellite R&D account which can be used to determine linkages between R&D inputs and outputs and the impact of new technologies on the economy. By separating out R&D research from other economic activities, identifying R&D as investment, and constructing R&D stocks, it is possible to better understand the role of R&D in economic growth. Direct and indirect rates of return to R&D could be estimated. Equally important in this process of accounting for the impact of R&D are improvements in our measurement of R&D inputs and outputs, particularly as there may be spillover R&D benefits. The research agenda implicitly laid out in this paper is significant, yet feasible. It is an effort that is worth beginning.

32) See for example Griliches, Zvi and Ian Cockburn, "Generics and New Goods in Pharmaceutical Price Indexes," American Economic Review, December 1994, pp. 1213–1232 and Berndt, Ernst R., Griliches, Zvi and Neal J. Rappaport, Journal of Econometrics, January 1995, pp. 243–268.

33) Pharmaceutical and computer-related companies are among the leading U. S. R&D companies. For a listing of the top 100 industrial U. S. R&D companies, ranked by size of R&D expenditures in 1996, see Appendix Table 4–23, p. A-144 of the National Science Board (1996), op. cit.

Methodology for Evaluating International Competitiveness of High-tech Industries

MU Rongping *

Abstract:

International competitiveness has been hot topics for decades, especially in the age of economic globalization. Considering competitiveness in nations, industries, enterprises and products, this paper will focus on evaluation of international competitiveness of Chinese high-tech industries, especially the industry with 3 digit-number code in the national standard classification system of industry.

On the basis of definition of high-tech industries and analyzing international competitiveness of the industries, the paper presents method for defining high-tech industries and framework for analyzing international competitiveness of the industries, including the indicators for evaluating the competitiveness. By exploring and implementing the methodology to monitor the international competitiveness of specific high-tech industries, we can provide strong support for the formulation or improvement of development strategies for high-tech industry and the policies concerned.

I. Introduction

International competitiveness has been drawing more and more attentions from both policy-makers and policy researchers since 1980's, especially in the age of economic globalization. Because of intensifying international competition, governments always want to find ways to improve their international competitiveness. The evaluation of competitiveness is the starting point of policy-making for strengthening competitiveness.

International competitiveness is usually reflected in four levels: (1) competitiveness of nations; (2) competitiveness of industries; (3) competitiveness of enterprises; (4) competitiveness of products. This paper will focus research on evaluation of international competitiveness of Chinese high-tech industries. However, it is difficult to discuss specific competitiveness mentioned above separately, be-

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cause all kinds of competitiveness are very often bound up with each other.

Many researchers¹⁾ have done lots of work in the fields of evaluating international competitiveness. For the national level, the methodology developed by WEF and IMD has drawn more and more attention in the world; At the industry level, M. Porter set up a framework for analyzing international competitiveness of industry with "diamond" model. However, few of them, theoretically and empirically, have touched the issues concerning evaluation of high-tech industry.¹⁾

In China some scholars²⁾ have shown some results concerning a methodology of analyzing international competitiveness of industry, but no one has tried to evaluate the international competitiveness of specific the industries in the middle level (for example, the industry with 3 digit-number code in the national standard classification system of industry). From the point of view of policy studies, the evaluation of international competitiveness of a specific industry is much more important than that of industry in general. By implementing the methodology to monitor the international competitiveness of specific high-tech industries, we can provide strong support for the formulation or improvement of development strategies for high-tech industry and the policies concerned.

High-tech industries are the major leading industries. In the past years, high-tech industries have contributed significantly to China economic development in terms of economic expansion, and national productivity, and have become increasingly important to the competitiveness of other sectors. To some extent, high-tech industries reflect the level of international competitiveness of a nation. However, it is difficult to define the concepts of both high technology and high-tech industry clearly.

This paper will focus on evaluation of international competitiveness of high-tech industry with three-digit number code and try to provide a research framework, including indicators for describing and evaluating the international competitiveness of high-tech industries.

II. Definition of Hi-tech Industry

One of methods to classify an industry is the so-called the Industrial Classification by Resources Intensity (ICRS), which means that industry will be classified according to the intensity of resources to be put into the production, in other words, how the industry relies on the production factors. So industries could be divided into capital-intensive industries, labor-intensive industries, and technolo-

1) International Institute for Management Development (IMD): *The World Competitiveness Yearbook*, 1996; **World Economic Forum (WEF)**: *The Global Competitiveness Report* 1996; **Michael E. Porter**: *The Competitive Advantage of Nations* 1990

2) See **Jin Pei** (chief ed.), *International Competitiveness of China Industry -Theory, Methodology and Practice*, Beijing: Economic Management Press, 1997; (**Di Ang-zhao**), *International Competitiveness* Beijing: Reform Press, 1992; **Fan Xiaoping**, *Indicator System for evaluating the competitiveness of firms*, China Industrial Economy, 1997(5).

gy-intensive industries. Generally speaking, high-tech industries are technology-intensive, so ICRS is very useful for the definition of high-tech industry.

OECD uses several indicators, which describe the technology contents of industries, to classify the industry into four groups, namely, industries with high technology, upper-middle technology, middle technology and low technology.

Chinese Scholars also have done lots of work in definition of the high-tech industries of China. Cai Li³⁾ (1993) uses 6 indicators to analyze 36 industries, and points out that Electronic & Telecommunications Equipment, Petroleum Processing, Instruments & Meters are the high-tech industries. Also she argues that part of Machinery, Petroleum & Natural Gas Extraction, Smelting & Pressing of Nonferrous Metal, Chemical Industry, Smelting & Pressing of Ferrous Metal, Medical & Pharmaceutical Products, and Transport Equipment, could become high-tech industries in the future.³⁾

China Science and Technology Indicators 1998 accepts the definition and classification of OECD so as to make the analysis results be comparable with that of OECD, which means that Aviation & Aerospace, Computer & Office Equipment, Electronic & Telecommunications Equipment, and Medical & Pharmaceutical Products are regarded as high-tech industries.

It is worthwhile to note that all methods for industrial classification should solve the difficulties in measurement of the indicators. In developed countries, many measurable indicators are available for classifying high-tech industry. But, it is very difficult to use the same method in China. Considering the difficulties in statistics and the level of industrial development, we suggest the development of a new methodology for definition of high-tech industries. In order to master the nature of high-tech industry in China, we mainly consider the following four aspects: (1) the technology contents of industry; (2) industrial distribution of high-tech products; (3) industrial distribution of high and new technology enterprises; (4) international standards such as classification of high-tech industries in OECD. Among them, *the technology contents of industry* and *international standards* are the major factors; the other two are less important, and are regarded as reference factors. The statistical system of the national torch program has had lots of experiences in statistics of high-tech products, especially in authenticating high-tech products and high-tech enterprises according to technology contents of products or enterprises. So the industrial distribution of high-tech product and enterprise is very helpful for high-tech industry classification. (Fig. 1)

3) Cai Li: *High-tech Economy*, Changchun: Jilin Science & Technology Press, 1995, pp. 129—132.

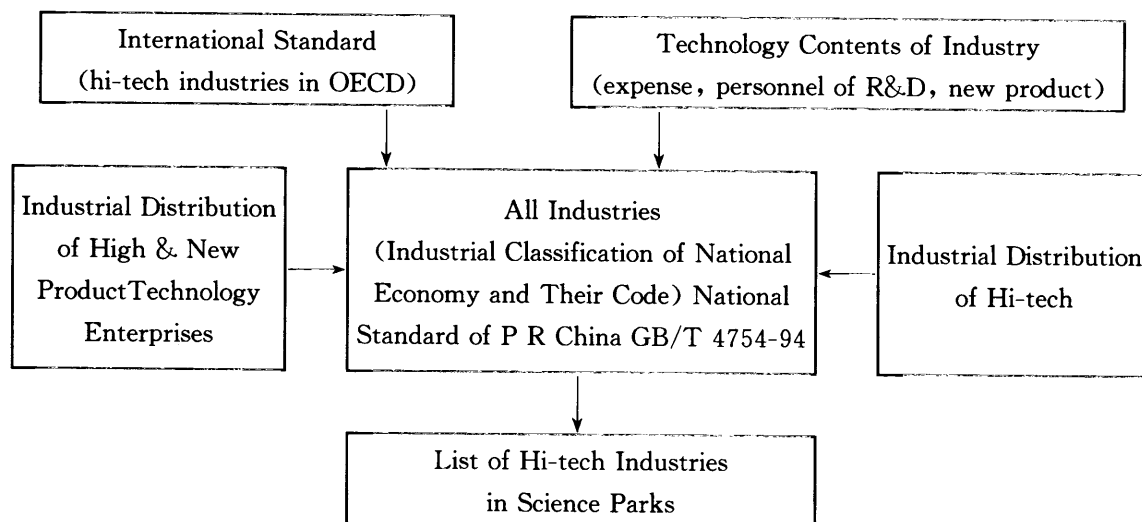


Fig. 1 Framework for Definition of Hi-tech Industries

The Measurement of the Technology Contents of Industry. In order to describe the technology contents of industry, we select four measurable indicators:

- the ratio of technical development persons to total employees
- the ratio of R&D expenditure to sales revenue
- the ratio of technical development funds to sales revenue
- the ratio of sales of new products to sales revenue

Because there is often some misunderstanding about R&D (the technical development in enterprises is often regarded as R&D). Besides, there are some differences in the limits of R&D expense between China and international standard, which means that statistical data concerning R&D could not be used without any analysis at present. So we choose "Technical development Person" instead of "R&D person".

In practice, we have calculated the ratios below according to four indicators mentioned above in three levels: (1) industries with two-digit number code; (2) industries with three-digit number code; (3) industries with four-digit number code. We selected as hi-tech industry, only those industries with three-digit number code. We choose a Standard Value for selecting hi-tech industry, and give a list of industries, which could be hi-tech industry. However, the final suggested list of hi-tech industry can be decided by considering two reference indicators as follows.

1. The Industrial Distribution of High & New Technology Enterprises in the Science Park System.

As a reference indicator, we have analyzed the industrial distribution of high & new technology enterprises in the Science Park System by using statistical data of 1996. The results show that high & new technology enterprises mainly concentrate in the industries of Technology Service, Computer Application & Service, Electronic & Tele-communications Equipment, Equipment & Meters & Culture & Office Machinery, Equipment for Special Purpose, Raw Chemical Material & Chemical

Products, Medical & Pharmaceutical Products, and Electric Equipment and Machinery.

2. The Industrial Distribution of Hi-tech Products. In order to definite the high-tech industries, we collect 5 lists⁴⁾ of high-tech products and have analyzed the industrial distribution of these high-tech products. The results show that there are three kinds of relationship between list of high-tech product and industry: (1) highly concentrated; (2) partly concentrated; (3) highly decentralized. We suggest that only those industries, in the list mentioned above could be concentrated, be considered high-tech industries.⁴⁾

By analyzing the industry list above, we can list Chinese high-tech industry as following:

Table 1 Part of High-tech Industry List suggested

INDUSTRY (IND.)	IND. CODE	INDUSTRY	IND. CODE
Equipment & Meters & Culture & Office Machinery	42	Electronic & Telecommunications Equipment	41
Medical & Pharmaceutical Products	27	Computer Application & Service	83
Electric Motor	401	Medical Equipment	365
Power Transmission & Distribution and Control	402	Aviation & Aerospace	377

From table 1 we can see that most high-tech industries in the list above are consistent with the OECD's high-tech industry list.

III. Indicators for Evaluating International Competitiveness of High-tech Industry

As we have had the list of high-tech industries, then we should find the indicators to describe the international competitiveness of specific industries with three-digit number codes. There are many factors, which affect the competitive capability, such as market scale, technology capability, industry policy, development of industries concerned. And also there are many ways, in which competitiveness was shown, such as productivity, value added of industries and so on. In order to evaluate the competitiveness, we explore a framework for analyzing the competitiveness as following (Fig 2):

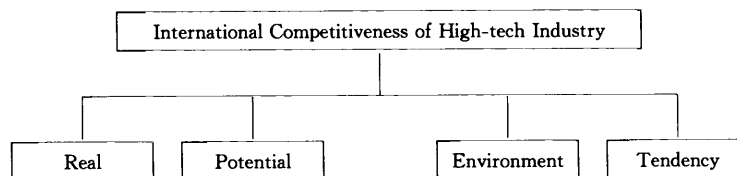


Fig. 2 Framework for analyzing the high-tech industrial competitiveness

4) See National High-tech Products List, by SSTC in 1997; High-tech Products List of Guangdong Province, 1997; High-tech Products List of Zhejiang Province, 1997; High-tech Products List of Hunan Province, 1995; High-tech Products List, by Department of Commerce of U. S. (DOC3). and which most high-tech products in the lists mentioned above could be concentrated, be high-tech industries.

1. Real Competitiveness

Real Competitiveness indicates the capability to transform potential competitiveness into competitive advantage under a certain competitive environment, and can be described with three indicators, namely: (1) Capability of Resources Transformation, (2) Marketing Capability, and (3) Technological Capability (Fig. 3).

Capability of Resources Transformation could be described with 4 indicators, namely: ① Labour Productivity; ② Ratio of Value added to Gross Industrial Output Value (Ratio of V. to G. I. O. V); ③ Ratio of Pre-tax Profits to Gross Industrial Output Value (Ratio of P. P. to G. I. O. V.); ④ Ratio of Pre-tax Profits to Capitals (Ratio of P. P. to C.).

Marketing Capability could be described with 4 indicators, namely: ① Market Share of Key Products in Aimed Market; ② Trade Competitiveness Index;⁵⁾ ③ Ratio of Export Income of New Product to Sales Revenue (Ratio of E. I. N. P. to S. R.); ④ Ratio of Export Price of Key Product to Import Price (Ratio of E. P. K. P. to I. P.).

Technological Capability could be described with 3 indicators, namely: ① Level of Industrial Key Technology (Level of I. K. T.); ② Advancement of Industrial Equipment; ③ Ratio of Sales Revenue of New Product to Product Sales Revenue (Ratio of S. R. N. P. to P. S. R.).

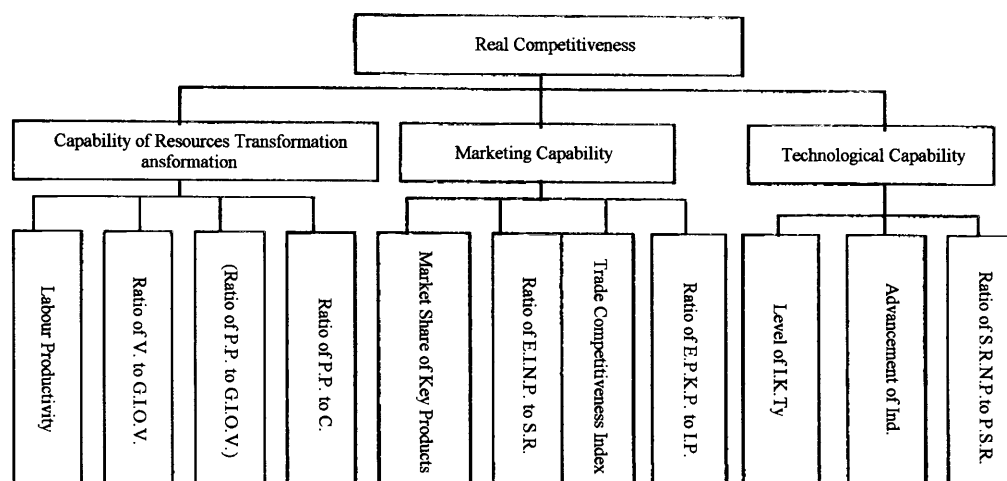


Fig. 3 Real Competitiveness

2. Potential Competitiveness

Potential Competitiveness measures the comparative advantage and other conditions to be deter-

5) Trade Competitiveness Index = (Export - Import) / (Export + Import)

mined by an industry. Potential Competitiveness could be described with 4 indicators, including: (1) Operation Status; (2) Technology Investment; (3) Comparative Advantage; (4) Innovation Capability (Fig 4).

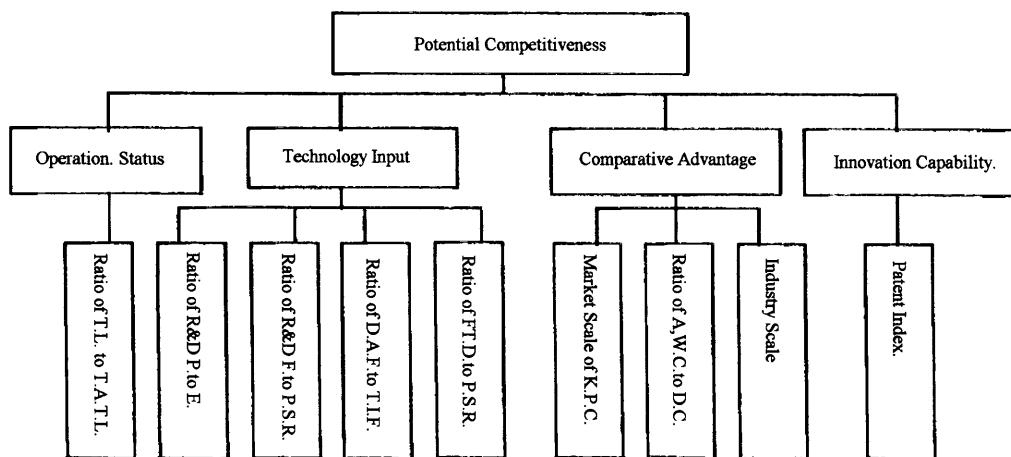


Fig. 4 Potential Competitiveness

Operation Status could be described with the indicator “Ratio of Total Liabilities to Total Assets” (Ratio of T. L. to T. A.);

Technology Input could be described with 4 indicators as follows: “Ratio of R&D Persons to Employees”(Ratio of R&D P. to E), “Ratio of R&D Funds to Product Sales Revenue”(Ratio of R&D F. to P. S. R.), “Ratio of Digest & Absorption Funds to Technology Import Fund”(Ratio of D. A. F. to T. I. F.), “Ratio of Funds for Technological Development to Product Sales Revenue”(Ratio of FT. D. to P. S. R.).

Comparative Advantage could be described with 3 indicators such as “Ratio of Average Wage in China to that in Developed Country” (Ratio of A. W. C. to D. C.), “Market Scale of Key Products in China” (Market Scale of K. P. C.), and “Industry Scale”.

Innovation Capability could be described with the patent index.

3. Competitive Environment

Competitive Environment indicates the development environment which is uncontrollable within an evaluated industry, and could be described with 5 indicators, including: (1) Technological Environment; (2) Trade Environment; (3) Political and Economic Environment; (4) Development of Related Industries; (5) Industry Policies (Fig 5).

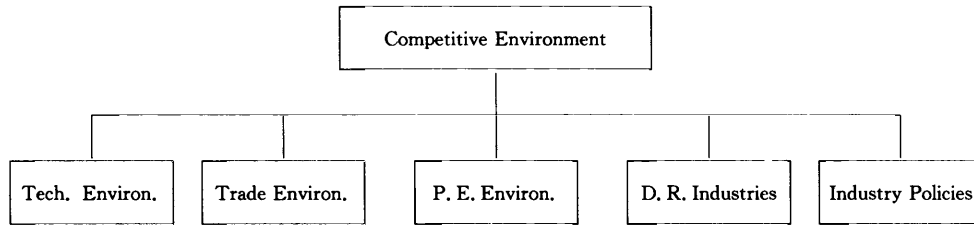


Fig. 5 Competitive Environment

4. Competitive Tendency

Competitive Tendency indicates a development tendency of international competitiveness, and could be described by 5 indicators, including: (1) Index of Capability for Resources Transformation; (2) Index of Marketing Capability; (3) Index of Technological Capability; (4) Index of Comparative Advantage; (5) Index of Competitive Environment (Fig 6).

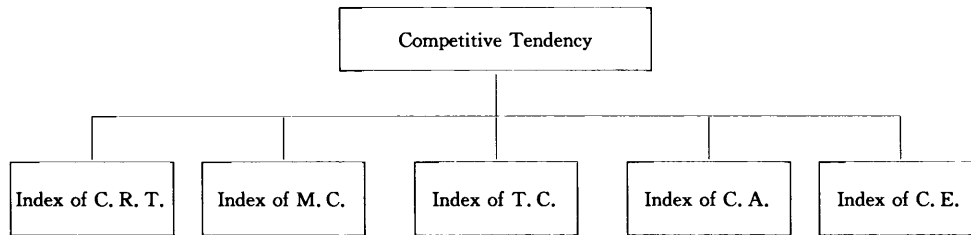


Fig. 6 Competitive Tendency

Index of Capability for Resources Transformation including: ①Index of Labour Productivity; ② Index of Ratio of Value added to Gross Industrial Output Value; ③Index of Ratio of Pre-tax Profits to Gross Industrial Output Value; ④ Ratio of Pre-tax Profits to Capitals.

Index of Marketing Capability including: ①Index of Market Share of Key Products in Aimed Market; ②Index of Ratio of Export Income of New Product to Sales Revenue; ③Ratio of Export Price of Key Product to Import Price; ④Trade Competitiveness Index.

Index of Technological Capability including: ①Index of Level of Industrial Key Technology; ② Index of Advancement of Industrial Equipment Index of Patents; ③Index of Ratio of R&D Persons to Employees; ④Index of Ratio of R&D Funds to Product Sales Revenue;

Index of Comparative Advantage including: ①Index of Industrial Scale; ②Index of Labour Cost; ③ Market Scale of Key Products in China; ④ Index of Ratio of Total Liabilities to Total Assets.

Index of Competitive Environment including: ①Index of Technological Environment; ②Index of Trade Environment; ③Index of Political and Economic Environment; ④Index of Development of Related Industries; ⑤ Index of Industry Policies.

5. Briefly Conclusion

On the basis of our analysis on international competitiveness, we think that the international competitiveness of hi-tech industries depends on its real competitiveness, potential competitiveness and competitive environment. Also we think that international competitiveness is a relative concept, so the selected indicators for the evaluation should be measurable and comparable. Finally, the paper presents a methodology and analysis framework for evaluating international competitiveness of hi-tech industries.

On the other hand, the paper develops a methodology for identification of high-tech industry, which is the starting point for evaluating the competitiveness of hi-tech industries. By using the methodology, we present a suggested hi-tech industry list. It is worthwhile to note that there is a big gap in the development level of hi-tech industries between developed countries and developing countries. The technical content of hi-tech industry in developed countries is very different from that in developing countries. So the standard we used for identifying hi-tech industry is also different from that used in developed countries.

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Indicators of International Science and Technology Cooperation and Interaction

Jennifer Sue BOND*

I am especially pleased to have been invited to this seminar which marks another important step in the scientific cooperation between our two great countries.

The 50th anniversary of the National Science Foundation, created on May 10, 1950, is fast approaching. Although half a century seems a very short time compared with the long and illustrious history of our host country, China, it provides an opportunity to look back and reflect on our past.

The National Science Foundation (NSF) was established to support research and development (R&D) and science and engineering education, primarily in U. S. universities and other non-profit organizations. From the beginning, it was recognized that an important responsibility for NSF would be to monitor and track the condition and status of the country's science and technology (S&T) enterprise. It is useful to note that even before the creation of NSF, U. S. policy makers recognized the importance of international cooperation in S&T. International cooperation has increased in importance in the intervening years.

In my presentation, I will provide some of the quantitative indicators that can be used to identify and monitor international S&T cooperation and interaction. It will illustrate some of the ways that the National Science Foundation's Science and Engineering Indicators Program tracks international S&T cooperation, and will provide some selected examples of data that are available for China. Not all of the indicators to be discussed currently have data available for China. However, they will be presented to illustrate possible new indicators that could be developed and analyzed for China.

Science and Engineering Indicators (S&EI) is the Congressionally, flagship report of the National Science Board-NSF's policy making body. The report is prepared by NSF's Science and Engineering Indicators program, which I direct. Decisionmakers in the Congress and in the Executive Branch of the Federal Government, as well as decisionmakers in academia, industry and nonprofit organizations use the *S&EI* reports, which are prepared biennially. These individuals value these reports as a source of quantitative data and analyses required as a basis for decisionmaking.

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The report that will be released early next year-*S&E Indicators-2000*-will be a special issue. In honor of the 50th anniversary of the National Science Board and the National Science Foundation, the Board has decided to develop a special historical theme for *S&E Indicators-2000*. The National Science Foundation Act of 1950, which President Harry S Truman signed into law on May 10 of that year, gave NSF the mandate, "to promote the progress of science; to advance the national health, prosperity, and welfare; and for other purposes."¹⁾ From the time of its creation, the collection, analyses and dissemination of quantitative information on the status of science and technology in the United States to has been an integral component NSF's overall responsibility. NSF's creation occurred near the end of the time of transition following the end of World War II in which the foundations of U. S. science policy was established and many of the principal issues and concerns comprised by that policy were articulated. The creation of NSF was an essential component of the Federal Government's organization to deal with those issues and concerns.

The *S&EI* reports provide information on the role of education in the U. S. science and engineering enterprise from precollege mathematics and science education through graduate education and beyond. They include information on scientists and engineers in the workforce and also provide special analyses of the academic sector and the industrial sector. Each edition since 1972 has featured a chapter on public understanding and public attitudes toward science and technology. *S&EI-2000* will include a new chapter on the social and economic impacts of information technologies.

As the Director of NSF's S&E Indicators Program, I have the privilege of having an overview of the various S&T trends that are reported in the biennial *S&EI* reports. I am also in a position to influence new developments and research on quantitative indicators. The data I will present in this paper are from the *S&E Indicators-1998* and updated and associated databases. One of the key cross-cutting themes identified in the *S&E Indicators-1998* was the rapid growth of globalization and international cooperation. This is well documented in the report's Overview chapter. The data and analysis in the forthcoming *S&E Indicators-2000* report, which we are finishing now, will show that international cooperation is continuing to grow. This trend is true for most countries and fields of science and engineering.

There are several indicators that can be used to measure S&E cooperation. Among them are;

- ◆ Alliances and partnerships
- ◆ Flows of students and scientists
- ◆ Co-authorship
- ◆ Scientific and technical literature
- ◆ Citation patterns
- ◆ Patents and licenses to use intellectual property.

1) *National Science Foundation Act of 1950*, Public Law 81-507 (Stat. 149).

In terms of alliances, the *S&E Indicators-1998* shows that industrial firms are developing international alliances and are using global research partnerships as a means of strengthening core competencies and expanding into technology fields that are crucial to maintaining market share. Since the mid-1980s, companies worldwide have entered into over 4,000 known multi-firm alliances involving strategic technologies. More than one-third of these alliances were between U. S. firms and European or Japanese firms. Most of the alliances were created to develop and share information technologies. Currently we do not have good data on alliances between U. S. and Chinese companies. This would be valuable information to have.

We do have much better data on the international flows of S&E students. In the past decade, foreign students have accounted for the large growth in S&E doctoral degrees in U. S. universities. The number of S&E doctoral degrees earned by U. S. and foreign students in U. S. higher education institutions grew from just under 20,000 in 1986 to over 25,000 in 1997 (See Fig. 1). However, only about 15,000 of these students are U. S. citizens. About 10,000 are foreign students and among these, half are Asian nationals. This is major contribution to scientific capabilities by the United States. At the same time it is also a benefit to U. S. universities who are not only training these bright young people but also having the benefit of them doing research and contributing in this way.

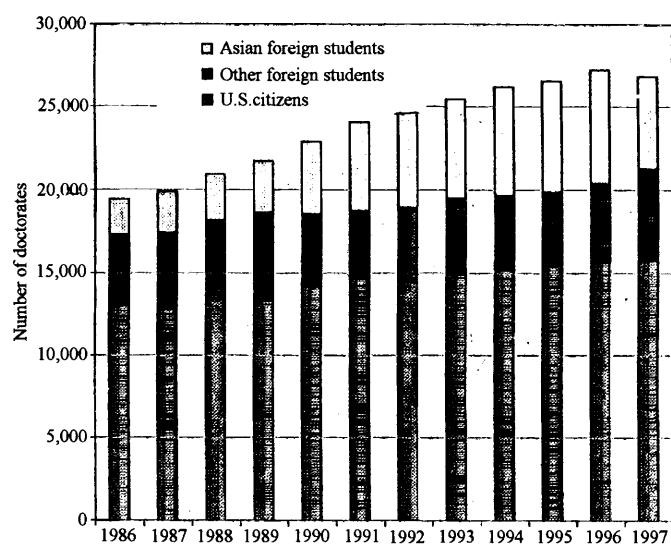


Fig. 1 U. S. S&E doctoral degrees earned by U. S. and foreign citizens

The United States is a major contributor to the education and training of Asian S&E students. NSF data show that the number of Ph. D. s in S&E fields obtained within Asian universities has steadily risen to about 19,000 in 1997. During the late 1980s and 1990s the number of Asian S&E doctorates granted in the United States rose substantially and reached more than 6,000. However, in the last year this number has decreased somewhat.

An examination of the number of Chinese doctoral students trained in the United States, the number is substantial, representing a cooperative contribution of the United States with China. (See Fig. 2) In the early 1990s U. S. institutions of higher education awarded more doctoral degrees in science and engineering fields than were awarded in China. However, since the mid 1990s China has greatly expanded the training of doctoral S&E students in China itself, greatly surpassing the number trained in the United States.

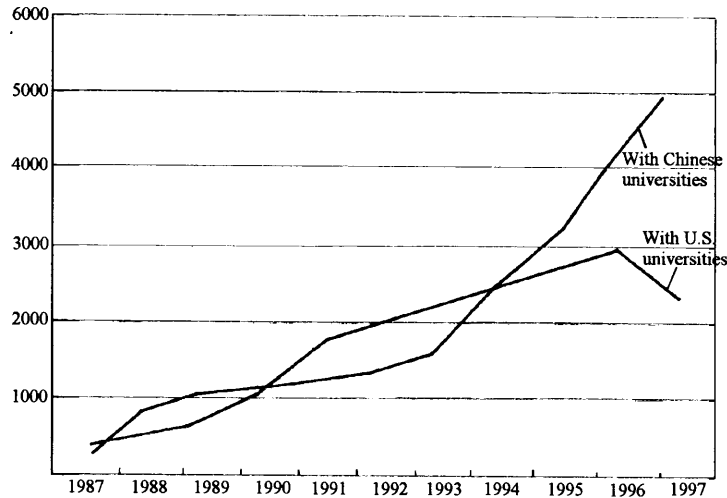


Fig. 2 S&E doctoral degrees earned by Chinese students within U. S. and Chinese universities

Where do the foreign S&E doctoral students go after graduation? For the period 1992–1996, the percentage of foreign doctoral recipients planning to remain in the United States increased: more than 68 percent planned to locate in the United States, and nearly 44 percent had firm offers to do so. Stay rates differ considerably by nationality. In 1996, more than half (57 to 59 percent) of S&E doctoral recipients from China and India receiving their degrees from an U. S. institution had firm plans to stay. A smaller percentage of those from South Korea and Taiwan (24 and 28 percent, respectively) accepted employment offers in the United States.

Many of the Chinese students educated in the United States plan to stay in the United States—at least for a period. (See Fig. 3) A special analysis of the 16,550 Chinese S&E students receiving their doctoral degrees from U. S. institutions during 1988 to 1996 shows that 85 percent planned to stay in the United States and almost half (48 percent) had firm offers to stay. Almost a third were staying for further training in universities in postdoctoral positions. Less than a fifth (17 percent) had firm offers of employment, 11 percent in industry, 5 percent employed in universities and only 1 percent in government. This pattern is typical of other countries' doctoral students, with the exception that Chinese students are more frequently taking postdoctoral positions for further training.

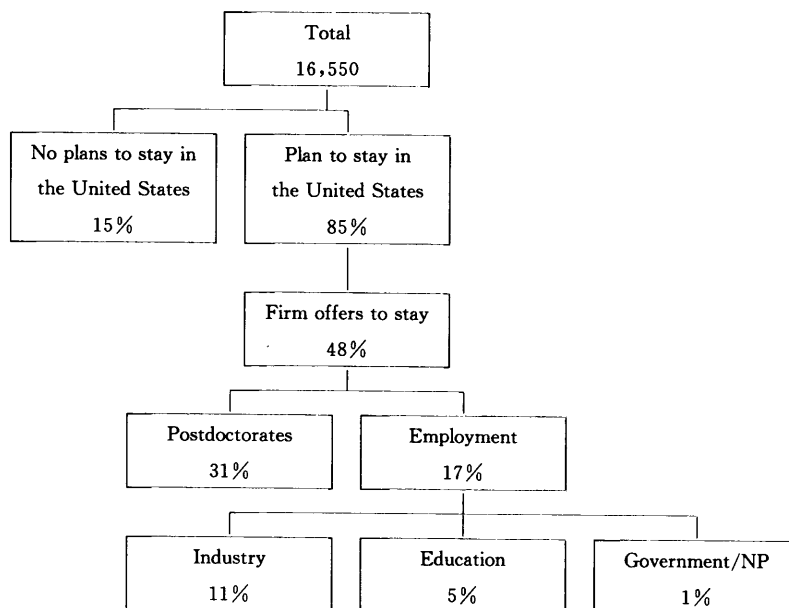


Fig. 3 Chinese S&E doctoral recipients: 1988—1996

The Chinese students who stay in the United States are obviously contributing to the research efforts in the United States and so are collaborating with US researchers in the United States. They are undoubtedly also contributing and co-authoring papers with their colleagues in China both while they are here and when they return to China as will be seen when we examine the co-authorship patterns.

Analysis of the world's most prestigious science and technology journals can shed light on international collaboration patterns. These analyses show a remarkable increase in international cooperation in most countries and fields. Since 1981, the overall number of articles published in a set of the world's most influential S&T journals²⁾ rose by almost 20 percent, compared with a rise of 8 percent in articles attributed to U. S. authors. This increase coincided with the strengthening of S&T capabilities in several world regions and countries including China. Europe increased its share of published output from 32 percent in 1981 to 35 percent in 1995, reaching a higher share than that of the United States. Asia's share rose from 11 to 15 percent over the period.

This increase in international collaboration in scientific publications is an important indicator of the globalization of science. In 1995, half of the articles in a set of journals covered by the *Science Citation Index* had multiple authors, and almost 30 percent of these involved international collaboration. A steadily growing fraction of scientific publications from most countries involved co-authors from other countries. From 1981 to 1995, while article output grew by 20 percent, the number of arti-

2) Note that this is a fixed journal set of the journals covered by the Institute for Scientific Information, Science Citation Index that has been further analyzed for the National Science Foundation by CHI Research, Inc. The exact numbers may differ from those in the Chinese S&T Indicators series, which cover a broader range of journals.

cles with multiple authors rose by 80 percent, and the number with international co-authors by 200 percent. These trends occurred in all fields. Fig. 4 shows the percentage of scientific and technical papers, in selected fields, with one or more U. S. authors which were coauthored by one or more residents of another country for the periods 1986–1988 and 1995–1997. Figure 5 provides comparable data for China.

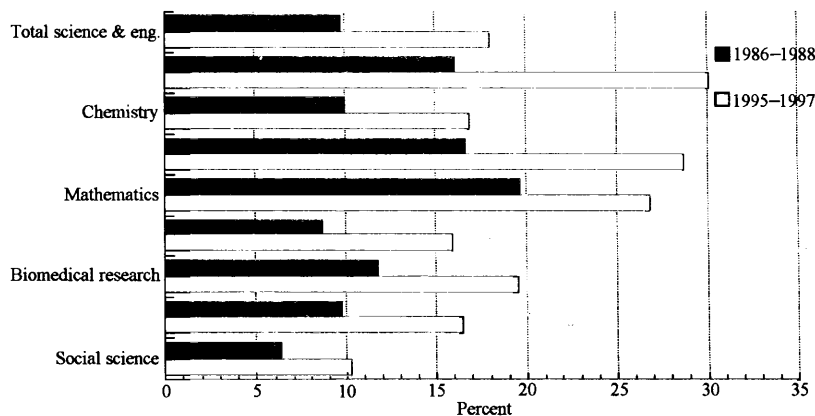


Fig. 4 Percentage of internationally co-authored scientific and technical articles, by field; United States 1986–1988 and 1995–1997

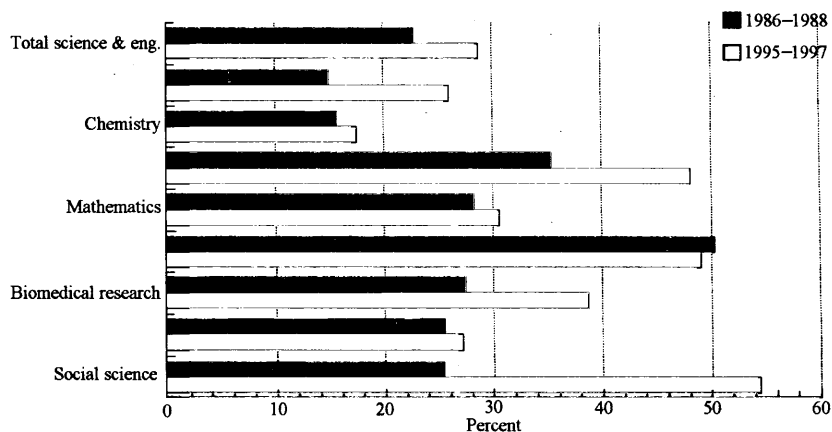


Fig. 5 Percentage of internationally co-authored scientific and technical articles, by field; China 1986–1988 and 1995–1997

For almost every country with strong international co-authorship ties, the number of articles involving a U. S. author rose strongly between 1981 and 1995. However, during this same period, many countries broadened the reach of their international collaborations, particularly within their respective geographical regions, resulting in a decrease in the U. S. share of the world's internationally co-authored S&T articles. In the Asian region, collaboration particularly involved China and the newly developing industrial countries. U. S. -Chinese collaboration in percentage terms decreased by almost half—from 45 percent of all the articles Chinese researchers co-authored internationally in 1986–1988 to 23 percent in 1995–1997. This was due primarily to a large increase in the number of articles jointly authored with researchers in Hong Kong.

Examination of the latest data from NSF's S&E Indicator database on co-authorship shows that international collaboration is continuing to increase in all fields for both U. S. and for Chinese researchers. The percent of internationally co-authored S&T articles in this select set of journals increased from 23 percent in the 1986–1988 period to 29 percent in 1995–1997. International co-authorship by U. S. researchers (see Fig. 5) also greatly increased, (albeit from a smaller base) almost doubling from nearly 10 percent in 1986–1988 to 18 percent in 1995–1997. This is noteworthy because both countries have large populations of their own national researchers with whom to collaborate. It is indicative of increased globalization and increased integration into an international S&T community. The advent and spread of information technologies certainly helps with the communication process and the ability to maintain ties with former professors and colleagues as well as new collaborators, regardless of the country in which they are living.

Citation patterns also mirror the global nature of the scientific enterprise, as researchers everywhere extensively use and cite research findings from around the world. U. S. scientific and technical articles as a whole are cited by researchers in virtually all mature scientific nations in proportions greater than the U. S. share of world output in chemistry, physics, biomedical research, and clinical medicine. U. S. articles in the remaining fields tend to be cited at or slightly below the U. S. share of world output.

Fig. 6 shows that U. S. researchers cite articles by other U. S. researchers even more than could be expected from the size of U. S. contribution to literature. Chinese researchers also cite U. S. articles about the same proportion as they do Chinese S&T literature. Chinese researchers also more frequently cite other Asian research articles to a greater extent than do U. S. researchers, indicating regional ties.

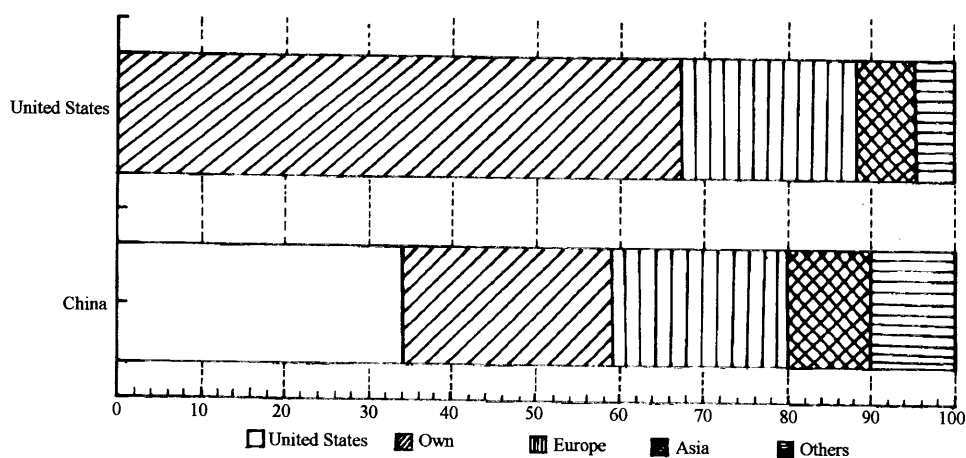


Fig. 6 S&T Citation Patterns of the United States and China

Foreign patenting activity demonstrates the global nature of technology as well. Even though China does not yet have a strong database on patenting activity this is a useful technology indicator to begin to track. It can show in which technical areas each country has strength and which markets

they intend to interact. Foreign patenting in the United States is strong and highly concentrated by country of inventor. Five countries—Japan, Germany, France, the United Kingdom, and Canada—account for 80 percent of foreign-origin U. S. patents. Several newly industrialized economies, such as Korea, are also increasing their patenting activity.

In summary, there is substantial growth in both the magnitude and breadth of international S&T cooperation in almost all countries and fields, and we have developed reasonable quantitative measures of these trends. International collaboration in science is a win-win situation. China and the United States have a long tradition of S&T collaboration; and hopefully this will continue to grow in the future. One of the goals of this workshop. I would like to note that NSF has had good collaboration with China in the field of S&T indicators and I hope that this will continue in the next century.

Thanks very much for inviting me.

Parallel Breakout Session I: Data Requirements for Policy-making and R&D

Commentary

David M. HART

Paper summaries

Sumiye OKUBO described a framework for measuring R&D and its returns, using data already gathered for the national income accounts. This framework would treat R&D as an investment and aggregate it across all industries. Her project is ambitious and would take several years to carry out, if it is funded. I found it extraordinary that R&D is not routinely treated as an investment, and the paper points out again how important it is for us to remember that our analytic categories are often constructed as a result of legal and political decisions, rather than professional or scholarly choices.

MU Rongping also described an ambitious framework that would require substantial funding and effort to implement. In his case, the object of analysis is corporate and industrial competitiveness in the high-technology sector. He describes a method for classifying industries as “high-technology” and then lists multiple measures for the analysis. These measures cover the real and potential competitiveness of firms and sectors as well as their environment.

Jennifer BOND drew on her broad knowledge of various types of indicators and indicators methodologies based, in part, on her experience as the director of NSF’s *Science and Engineering Indicators* unit to provide a picture of international scientific cooperation in and between the U. S. and China. She focused particularly on flows of people and production of papers, and her paper thus nicely complemented John MCTAGUE’s. The data show that China is rising in international stature and, while the brain drain from China to the U. S. and other industrialized countries is not reversing, the potential for such a reverse flow may well be being created. BOND also emphasized the essential role that international cooperation has played in advancing indicators methodologies in several critical areas, and pointed to the need for such collaboration in developing new types of indicators useful in the future: e. g. , reliable indicators of international scientific mobility.

Comments

These papers show first of all the critical importance of measurement and methodologies for research in science and technology policy. All of us in the field are dependent on this type of work for devel-

oping policy recommendations we are only as good as our underlying data. There is no substitute for public funding and public provision of such data, and it's incumbent upon those of us in the field to speak up on its behalf.

Second, we might want to reflect critically on whether the data that we are supplying intersect sufficiently with what policy-makers need. I was not convinced from our discussion that the linkages are as tight as they should be. That's not to say that we ought to tailor all data production to serve policy-makers autonomous research deserves a place but we should make sure that they are among the users who find the data useful to have.

Third, I think we need to work harder on measuring the outputs of R&D and the outcomes that reflect the impact of science and technology on society. We've done a very good job measuring the inputs to science and technology, but that's not what policy-makers care most about. Some of the work presented here moves in this direction. At the same time, we need to acknowledge that as we move from inputs to outputs and especially to outcomes, the error bands around our measurements inevitably grow.

Finally, these papers suggest the importance of utilizing multiple measures no matter what subject we are tackling. Professor MU's paper was particularly useful in this regard, although (as he would admit) he is a long ways from making the measurements that he proposes in the paper.

Plenary Session II: Human Resources for Science and Engineering

The Knowledge-based Economy and Its Challenge to China's High Education

XUE Lan *

Abstract The rise of knowledge-based economy has posed many opportunities as well as challenges to higher education institutions in China. The major difficulties in China's higher education system lie in its heritage from a planned economy where the central government played key roles in determining everything from faculty salary to the number of students to be admitted into a specialty in a particular university. In order to meet the challenges of the knowledge economy in the coming century, the government must take bold actions to reform the higher education sector in China. The first step of the reform should focus on clarifying the respective roles and powers of the Ministry of Education, other central Ministries, provincial and municipal governments. At the same time, the government should give universities full financial and managerial autonomy, allowing them to set their own academic programs, admit students, charge tuition fees, all according to the market needs and their capabilities. Also, the government should create a "friendly environment" for individuals and institutions, which are interested in establishing private universities.

I. Introduction

A key feature of the emerging global knowledge economy is the rise of information technology and the rapid increase in the amount of information and knowledge being generated and used. Our society has become more dependent on knowledge than any other previous generation. Knowledge, particularly knowledge of modern science, technology and management, has become a strategic resource and the most important factor for economic growth. Industries based on high and new technologies including information technologies, have become the backbones of a knowledge-based economy. At the same time, our natural and social environments are constantly changing. The cycle of knowledge obsolescence is shortening. International competition is increasingly based on the development of human capital equipped with knowledge and moral principles. The shift of economic fo-

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cus to knowledge signifies another major transformation in human history and will have a profound impact on the landscape of the world economy in the 21st century.

The rise of the knowledge-based economy has posted many opportunities as well as challenges to higher education institutions in China. First, there is an increasing demand for highly trained personnel to help China make the transition from a planned economy to a market economy, from an economy mainly based on capital and labor to one based on knowledge and skills. China needs a new generation of educated people with integrity, knowledge, and creativity. Second, universities in China not only have to generate and disseminate new knowledge, they also have to play active roles to foster better knowledge transfer from academia to commercial market. This is mainly because, as a developing economy, China's industrial R&D capabilities are limited. Third, China's universities have to face the increasing social demand for lifelong learning in the coming century. Continuing higher education service will become a major knowledge-intensive industry.

All these opportunities demand a new higher education system—a system open to those who are willing to learn and a system flexible enough to adapt to the rapid changes. Such demand puts great pressure on the internal structure and operations of the higher education system in China. Unless fundamental changes are made, it will be impossible for the current system to meet these challenges. In the following discussion, I will focus on the problems inherent in China's current higher education system and discuss ways to change it so that China can be prepared for the challenges of the knowledge economy in the coming century.

II. Challenges to China's higher education system

The major difficulties in China's higher education system lie in its heritage from a planned economy where the central government played key roles in determining everything from faculty salary to the number of students to be admitted in a specialty in a particular university. The autonomy of Chinese universities is much less than state-owned enterprises in other industries. At the same time, the environment where universities operate has dramatically changed to one that is very market oriented. The mismatch between the centralized system and its market-oriented environment has created many tensions and pressures that have prevented China's higher education system from adapting itself to meet the challenges of the coming knowledge economy.

1. Great imbalance between demand and supply in higher education

China began to rebuild its higher education system after a destructive decade during the cultural revolution (1966–1976). By 1997, China had 6 major forms of higher education services enrolling over 15 million students:

While these numbers are quite impressive, one must put them in perspective. First of all, only a little over 3.3 million students were in regular higher education institutions (equivalent to universities

and colleges in the US). In many people's mind, educational services offered in these institutions are what higher education is all about. It is in this category that enrollment competition has always been strong. In 1998, these institutions could only take one third of over 3 million applicants, which excluded those who wanted to apply but were not qualified since they had either quit high school or did not go to high school.

Table 1 China's higher education system

Form of Higher Education Service	Number of Institutions	Number of Student Enrollment
Regular Higher Education (other forms of higher education offered by these institutions)	1020	3,173,800 1,489,500
Continuing Higher Education Institutions	1107	1,235,000
Military Higher Education Institutions		169,000
Specialty Examination Preparation School	157	94,000
TV University		250,000
Registered Students to take National Higher Education Qualification Examination		9,150,000

Also, one must take China's huge population into account. Table 2. Shows some general indicators of higher education for countries of different income categories. It is clear that China's gross enrolment ratio is only slightly higher than countries of low income category, while much lower than countries in other categories. Further, if one looks at the percentage of adult population with higher education background, China's level was even lower than that of the low income category. While some improvements have been made in the last few years, the overall situation has not changed.

Table 2 A comparison of higher education indicators for countries of different income categories (early 1990s)

Income categories	Per Capita GNP	Gross Enrolment (%)	# of enrolled students / 10,000	% of population over 25 years old with higher education
Low income	430	4.5	417.7	2.7
Lower-middle income	1670	15.8	1946.0	8.8
Upper-middle income	4260	22.4	1446.1	9.9
High income	24930	53.0	3901.2	27.6
China	620	5.7	440.4	2.0

(Source: He and Lan, 1998)

The consequences of this huge gap between demand and supply in higher education are three folds. First of all, lack of highly trained personnel has been a major bottle-neck in China's effort to make

the transition to a market economy and knowledge-based economy. Second, the strong competition to get into university has put a great pressure on high schools to design their educational programs to prepare students to score high in the national entrance examination, rather than to educate students with knowledge and skills appropriate for them.

Third, this gap builds tensions between the general public and the higher education system. When such tension accumulates to a certain level, the relevant government agency would have to give in and make concessions, namely increasing admission numbers. For example, from 1985 to 1991, the annual enrolment number of students in regular higher education institutions was around 600,000. A great jump was made between 1992 and 1993 when this number was increased to around 900,000. In 1999, to escape the great social pressure on the higher education system, the Ministry of Education announced, a few weeks before the national entrance examination days, that it would increase the enrolment this year by over 40%. On the other hand, such leaps and jumps have also created problems for universities and, in a few years, graduates who are looking for jobs.

2. Mismatch between what university trains and what society needs

While many people have advocated an increase in the number of higher education enrollments, few have looked into the problem of mismatch between what university trains and what society needs. In fact, as China's labor market becomes more open, the over-supply of graduates in some fields and the short-supply of graduates in others have also become apparent.

Table 3 is created with the information provided by Ministry of Education in April 1998 for universities under the administration of the Ministry (Xue, et. al, 1999).

**Table 3 Supply-demand ratio for graduates from different types of universities
(Supply : Demand)**

	Overall Ratio	Ratio for graduates with bachelor degrees	Ratio for graduates without bachelor degrees(<4 years)
Comprehensive Universities	1 : 1.59	1 : 1.74	1 : 0.38
Engineering Universities	1 : 3.27	1 : 3.64	1 : 0.55
Foreign Language Universities	1 : 1.13	1 : 1.28	1 : 0.39
Normal Universities	1 : 1.11	1 : 1.19	1 : 0.92

As one can see, there is a great variation in terms of supply and demand ratio for different kinds of universities and for different levels of training. While, there are over 3 jobs waiting for someone with an engineering bachelor degree on average, a graduate with a bachelor degree from a normal university would have little choice but to take the job available. For people without a bachelor degree, there is an over supply of graduates in every category.

Obviously, the table gives only a general picture which conceals great variations among different universities within any particular category and variations among different disciplines. For example, for normal universities where the overall supply demand situation was not very good, there was a great demand for graduates in Chinese language, English, physics, and computer software. On the other hand, for engineering universities where the overall supply demand situation was quite favorable, the market for graduates in ocean engineering, precision chemical engineering, systems engineering, chemical engineering, biochemistry was very weak.

3. Lack of autonomy in university management

Today, the autonomy of China's universities is still very limited, a situation quite similar to the situation many state-owned enterprises (SOEs) faced 15 years ago. Universities' academic offerings have to follow an academic discipline directory determined by the State Council's Committee on Academic Degrees. The number of students a university intends to admit will also have to be submitted first to higher authority for approval. Under such a system, it is no wonder that there is a mismatch between what universities train and what society needs.

While government funding for a university is typically much less than it needs to cover even the basic operations, the relevant government agencies also set the upper limit of tuition a university can charge, which does not even cover one third of the costs. Partly as a result of their financial difficulties, many universities have been trying to find other ways to make ends meet, such as directly running enterprises. Faculty salaries are set according to a national standard, which are often many times lower than their market value. As a result, many young faculty members have left their teaching jobs for opportunities outside the academia. For those who are still in, many find other ways to earn extra, often at the cost of teaching or research quality.

In addition, like SOEs, a university in China typically has to run everything on campus, from a hospital and cafeterias to schools from K-12. On the other hand, most administrators of Chinese universities are experts in their own academic specialties, not professional managers. The combination of both often results in low efficiency and mismanagement in university administration.

III. Reform on China's higher education system: what needs to be done?

In recent years, the government has begun to put great emphasis on S&T and has education and made a real effort to alleviate the difficulties discussed above. For example, the government supported a reform program proposed by the Academy of Sciences with an appropriation of over 5 billion Yuan. The program is aimed at restructuring the research institutes of the Academy to better meet the challenges of the knowledge economy. The government also supported an action plan proposed by the Ministry of Education to revitalize China's education for the 21st century. The Ministry of Education has also embarked on many reform initiatives aimed at improving the structure and efficiency of China's higher education system. However, the success of these efforts has been

quite limited since most of them have not touched on the root problem of the system.

The fundamental challenge of China's higher education system is how to orient the system from an input-and supply-driven model rooted in a planned economy to an output- and demand driven one rooted in a market economy. There is a great similarity between this reform and the reform of SOEs. This similarity also signifies the magnitude and complexity of the difficulties involved. In the following, I will outline some overarching recommendations on how China should push forward the higher education reform to meet the challenges of the knowledge economy.

The first step of the reform should focus on clarifying the respective roles and powers of the Ministry of Education, other central Ministries, provincial and municipal governments. As a principle, government should gradually get out of micro-management of the academic programs and administrations in universities. Instead, government should shift its attention to improve the operating environment of universities, set policies to redistribute resources to those disciplines, institutions, and regions where special attention is needed, and support and nurture professional and intermediate organizations to monitor the quality of academic programs, and to establish accreditation standards and procedures.

At the same time, the government should give universities full financial and managerial autonomy, allowing them to set their own academic programs, admit students, charge tuition fees, all according to the market needs and their capabilities. In general, government funding for universities should be gradually reduced so that the limited resources can be more efficiently used to establish centers of excellence in needed areas, and to rectify market failures for some disciplines, institutions or regions.

Also, the government should create a "friendly environment" for individuals and institutions, which are interested in establishing private universities. The government should set standards and regulations, which are open and transparent, for such initiatives.

A major difficult is how to improve university management. One hope is that, as soon as the market is open for competition among different universities, it is likely that individual universities would have to find ways to improve their academic quality and operating efficiencies. The government can facilitate such changes by establishing training center for university administrators and by providing information on successful examples.

In a few months, the human society will enter into the 21st century, the beginning of a new millennium. It is already clear that the coming century will be more knowledge intensive than ever. Universities will become probably the most important institution in such an era, to provide advanced training, generate and make use of new knowledge, and promote cultural exchanges and international development. These roles are exciting, but also challenging! Universities in China have no choice but to join this trend, to become the herald of the coming knowledge society in China.

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Opportunities for Chinese and American Universities in the Knowledge-based Economy

Richard C. ATKINSON*

It is a pleasure to be here on this occasion, the twentieth anniversary of the first agreement in history between the People's Republic of China and the United States for the exchange of scientists and scholars. That agreement was also the first document ever signed by the two governments, and I am proud that, as the director of the National Science Foundation, I was the signator for the United States. The exchange came at a very critical and sensitive moment. I believe history will show that the exchange of scientists and scholars played an important role in the developing relationship between the two nations. Some people may be less aware of that agreement than others, in part because shortly thereafter the doors between the two countries opened wide. But at the time the agreement was a key signal from both countries that they were ready to take a new direction in their dealings with each other.

Today, twenty years later, it is gratifying to see the growing interest that scientists and government officials in China have shown in the contributions of basic research to their country's overall development. This science policy seminar is a fitting tribute to the crucial role that scientific ties established two decades ago have come to play in the relationship between our two nations.

I believe that building a strong foundation of basic research will ensure China's future economic competitiveness. This approach has been used with success in the United States for over 50 years. How this focus on basic research evolved, and the role that research universities play in spurring American economic growth, are the principal themes of this lecture. I will conclude with some thoughts about the challenges Chinese universities face in today's knowledge-based economy.

The term "knowledge-based economy"-sometimes called the "new economy"-refers to a set of industries whose main products or services use information to decrease costs and create new opportunities for growth. Generally speaking, the industries of the new economy tend to produce jobs more rapidly and with higher salaries, increase productivity growth faster, and provide greater profits for employers than the "old" economy. These high-technology industries rely on a constant infusion of new knowledge to stay competitive, and the principal source of such knowledge is basic research. The California economy provides a striking example. Its recovery from the economic recession of

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the early 1990s depended on knowledge-driven businesses and jobs that didn't exist 15 or 20 years ago—biotechnology, telecommunications, and multimedia, for example.

The evidence regarding the relationship between research and development (R&D) and economic growth in the United States is overwhelming. As recently as the early 1970s, there was no substantial economic analysis of the relationship between investments in R&D and economic development. When I served as director of the National Science Foundation in the 1970s, we were well aware of the lack of such economic data in making the case to the Congress for federal support of research. And we realized that most of our arguments about how R&D affected economic growth were based on little more than anecdotal evidence. Accordingly, we initiated a special research program at NSF focused on just that issue—the relationship between investments in R&D and the growth of the American economy.

In the intervening 25 years, a substantial body of research has led to a development in economics called “new growth theory.” This work was nicely summarized in a 1995 report of President Clinton's Council of Economic Advisors: 50 percent of the growth in the American economy in the last 40 years has been due to investments in research and development. Obviously, the private sector is a major driver of R&D, but federally funded research at universities also plays a key role. The report points out that when federal investments in university research increase, there is—with an appropriate time lag—a corresponding increase in private-sector investments. There is now a well-understood link between university-based research and industries' R&D efforts.

As I mentioned, the State of California provides one of the best examples of this linkage. In the early 1990s, the state endured one of the worst economic recessions in its history. California in prior periods had entered economic recessions later, and come out much earlier, than the rest of the United States. But in the 1990s this traditional pattern broke down. California suffered a brutal economic downturn fueled by tremendous cutbacks in defense and aerospace—a loss of jobs that resulted in a dramatic drop in the tax revenues of the state.

What has happened in the past few years? California has come storming back from the recession. Why? New jobs have been created at a fast rate. Where are those jobs coming from? From a particular type of activity: high technology. And these high-tech enterprises are not the vast IBMs and AT&Ts of the world. The companies that pulled California out of recession are small, entrepreneurial, high-tech ventures. These companies (and their technologies) can be traced directly to the research universities of California, both public and private.

Biotechnology, for example, a booming industry in California, traces its success—in fact its very existence—to research programs that came out of the state's universities. Digital telecommunications is another case in point. It could not exist at its current scale and scope without the California universities that produce the research and educate the engineers and scientists essential to keeping this industry on the cutting edge.

California succeeded in its remarkable economic comeback because it possessed four advantages essential to the new economy: 1) world-class research universities that encourage faculty—and allow them to benefit financially—when they are involved in research that leads to the development of new technologies; 2) a supply of entrepreneurs experienced in launching and developing high-technology businesses; 3) venture capital and other sources of private investment in early stage business ventures; and 4) the accounting, legal, and other ancillary services needed by start-up companies.

I would like to mention a concrete example, one that I am familiar with because it began while I was chancellor of the San Diego campus of the University of California (UCSD). In the early 1980s, the San Diego region was in the midst of a painful economic transition created by the demise of many of its defense-related industries. It was clear that something needed to bridge the gap, but what? My colleagues and I decided that UCSD had to play a more aggressive role in regional economic growth, specifically in the high-technology and biotechnology areas. Our view was that small, high-technology corporations were the most likely candidates to fill the economic vacuum that followed reductions in defense contracts to many San Diego corporations. UCSD had specific strengths it could contribute to the high-technology sector: the campus is one of the nation's top recipients of federal research funding; it was home to strong science departments and an excellent school of engineering.

We expanded the breadth of UCSD's basic research capacity, creating—in cooperation with industry—interdisciplinary research centers in such areas as magnetic recording, molecular genetics, wireless communications, and structural engineering. We reinvigorated our technology transfer programs in the science and engineering departments. And we created a program called UCSD CONNECT, which had as its goal not only technology transfer but also nurturing the business support infrastructure that has proven essential to small entrepreneurial firms. UCSD CONNECT draws on expertise across all campus departments and from all professional sectors. It has served to fill a critical gap in San Diego's business infrastructure, linking local high-tech entrepreneurs with financial, managerial, and technical resources.

What this means, for example, is that UCSD CONNECT will act as an agent on behalf of small companies to help them locate investors and find the research they need to develop new products. Working with start-up companies as early as the business plan stage, UCSD CONNECT will help an entrepreneur find contacts for raising capital, forming strategic alliances, gaining marketing and management expertise and technical advice. UCSD CONNECT is often referred to as an “incubator without walls” because it has nurtured so many successful businesses in San Diego.

UCSD CONNECT is just one example of the kind of help UC is committed to providing. There are similar efforts on every one of UC's nine campuses to bring venture capitalists and people from the industrial sector together with scientists and engineers on the campuses to move UC research ideas

into application.

Two years ago, the University held a statewide conference on technology transfer, bringing people from UC together with colleagues in government and in industry to examine how we can do more to facilitate the transfer of technology. In response to the business community's concerns that California is not producing enough computer scientists and engineers, between now and 2005 we are committed to increasing enrollments in engineering and computer science (at both the undergraduate and graduate levels) by 50 percent across the UC system.

And we have established a program—the Industry-University Cooperative Research (IUCR) program, now in its fourth year—which seeks to identify the most promising research areas for new products that, in turn, create new jobs. The IUCR program builds research partnerships involving industry and UC faculty. Let me explain briefly how it works.

A UC researcher joins with a scientist or engineer from a private company to formulate a research proposal. A panel of experts drawn from industry and academia selects the best proposals for funding. Industry investments are partially matched with University funds. In just three years, the investments by industry and UC have totaled more than \$100 million for new research undertaken by University faculty and students. An important feature of the program is the opportunity for graduate students to participate in research. It would be difficult to overstate the crucial link between research and graduate education in American universities. Graduate students participate in all aspects of faculty research projects. This experience is an essential part of the educational process for graduate students that produces both excellent young faculty for universities and R&D leaders for industry. In the case of the IUCR program, graduate students learn firsthand about industry's needs and its opportunities. And industry gets the benefit of some of the world's brightest young minds.

Two-thirds of the 323 companies currently participating in the IUCR are small businesses. A particularly valuable benefit for them is the opportunity to work with UC faculty on multidisciplinary research that would be difficult or impossible to pursue in the private sector. Research supported by the IUCR program lays the foundation for next-generation technologies; it provides hundreds of UC students participating in the research a window on future career opportunities. The six industrial sectors that currently participate—biotechnology, communications, information technology, microelectronics, multimedia, and semiconductor manufacturing—are all critical to the California economy.

There is growing interest in programs like these not only in California but also throughout the United States. The impetus to greater linkages between universities and industry grows out of a long-standing American belief that universities should not be divorced from society, but should be involved in helping solve society's problems.

The United States is unusual in the degree to which it relies on universities to perform basic research. The roots of this phenomenon date back over 50 to World War II. Near the end of the war, President Roosevelt turned to his science advisor, Vannevar Bush, for advice about the future of American science. Bush's report, which appeared shortly after President Roosevelt's death, was entitled "Science: The Endless Frontier." As the title suggests, Bush viewed science as a vast frontier of opportunities to serve virtually every aspect of the national welfare. His report set the stage for the modern era of science and technology in the United States.

What were the arguments that Vannevar Bush put forward? First of all, he asked "Who should fund the research and development effort of the United States?" Let me make a few distinctions here.

For simplicity of expression, I will use the terms basic research, applied research, and development. Basic research is not focused on applications; the terms "curiosity research" and "discovery research" are sometimes used to describe it. It is driven by a sheer interest in the phenomena rather than potential applications. But basic research may reach a stage where there is potential for application and accordingly a need for applied research and, in turn, the development of new products and processes. Bush argued that applied research and development should be done by the private sector, by industry. But he also argued that the private sector would not provide adequate funding for basic research. In essence, he believed that private market mechanisms ensured that industry would invest in applied research and development, but that those same private market mechanisms would not generate adequate investment in basic research. Thus, he concluded that the funding of basic research was an obligation of the federal government.

The second question he asked was "Who should perform R&D activities?" Applied research and development, he said, is a private-sector responsibility; the private sector could be relied upon to perform that kind of activity. Who should perform basic research? The Bush concept, founded on the experiences of World War II, was that American universities should be the principal performers of basic research; and as noted above the federal government should provide the funds for that work.

Then there was a third part to Bush's analysis. He believed that basic research should be funded through a peer—review process. Individual scientists should make proposals for research projects and a group of peers—leading scientists from around the country—should evaluate these proposals and decide which to fund and which not to fund.

Federal science agencies in the United States do not provide unrestricted block-grant funding to universities. Rather, individual scientists submit proposals that request funding for specific research projects. A scientist's proposal is then sent to other scientists for their evaluation and judged competitively against other research efforts. This evaluation—the peer review process—is the critical factor in ensuring that the best science is funded.

Those were Bush's arguments: Applied research and development should be funded and conducted by the private sector; basic research should be performed in universities and be funded by the federal government via a peer-review process. The Bush model created a sea-change for American universities. Before World War II, universities were peripheral to the R&D enterprise. Today they are at the center of American research activities, thanks in large measure to an extraordinarily successful partnership with the federal government. As a result, both the research enterprise itself and the U. S. economy have prospered. I do not believe it is an overstatement to say that when the history of the last half of the twentieth century is written, the role research universities have played in the American economy will be regarded as one of our greatest accomplishments.

In recent years, there has been much discussion in the United States about the need for a new national science policy, on the premise that Bush's 50-year-old vision cannot provide a blueprint for the twenty-first century. It is true that some of the arguments in Bush's report are now questionable, some of the issues he considered important are of interest only to students of the period. What remains pertinent is his vision of the role of government in research, including his assertion that the federal government has both the authority and the obligation to support basic research. More boldly, by arguing for the primacy of basic research supported according to norms set by scientists themselves, Bush implicitly asserted that universities defined the U. S. research enterprise. Bush gave them pride of place at the center because, as he argued, they had the potential to energize the entire system.

In spite of these remarkable successes, there is a concern in the United States today that federal funding for basic research will decline as the government struggles to balance its budget. The President of the United States and the Congress have reaffirmed their commitment to keep the federal budget balanced and to use a part of the surplus to reduce the national debt. Although some of the predictions about draconian cuts in federal funding for research have not so far materialized, this remains a matter of concern to universities throughout the nation.

The potential erosion of federal support for academic research is worrisome precisely because of the central role universities play in the overall R&D effort. Could industry take their place as the vital center of the American research enterprise? The evidence suggests not. As recently as a decade ago, several large U. S. firms performed significant basic research in their corporate laboratories. Today, virtually all industrial research focuses on the solution of specific problems, often by building on the results of university research. AT&T and IBM have essentially pulled out of basic research; both companies have come to the view that they are not wealthy enough to support basic research—at least not at the level they once did. In the United States we are relying more than ever on universities for the basic research that will ultimately fuel our economy. A recent statistic sums it up: Seventy-three percent of the papers cited by U. S. industry patents are based on publicly supported science, authored principally by university scientists; only 27 percent are authored by industrial scientists.

I am more optimistic than many of my colleagues that the federal government will find a way to continue funding university research at a reasonable level. Most political leaders in the United States who have thought about these issues——Democrats and Republicans alike——have concluded that support of our research enterprise is critical to the national interest, and therefore sound federal policy.

In its simplicity and flexibility, Bush's report remains a model for science policy in the United States. But does Bush's model have any relevance for contemporary China and its universities?

Obviously, no model can be imported wholesale from one country into another. China is finding its own way and its own solutions to the challenge of putting knowledge to work in the economy. But however solutions differ, more and more nations are coming to the realization that their universities are priceless sources of ideas that can create jobs, give birth to new industries, and stimulate the productivity growth that will enable them to create a better life for their people.

Among China's advantages today are growing encouragement for private enterprise and entrepreneurship within the country, and increasing interest among foreign investors in China's strengths in such areas as software, materials science, and biotechnology. One example of this interest is Microsoft's and Intel's decision to establish research centers here. Most important of all are the incredible resources China possesses in its universities and in its talented young people. Many of these young people have studied at foreign institutions and have experiences that will be very valuable to them in today's international marketplace.

This point brings me back to where I began——to the importance of international exchange in educating new generations of scientists and engineers who can function effectively in other countries and other cultures. This science policy seminar will surely reveal new directions our countries need to take, but it is also a wonderful reminder of how far we have come from those tentative contacts of 20 years ago.

We are living in one of history's most productive eras of intellectual discovery. From agriculture to medicine, from aerospace to computing, science is experiencing a series of revolutions that are re-making our ideas of what is possible. These revolutions are occurring on the campuses and laboratories of research universities every day. We have only just begun to tap the possibilities of this explosion of knowledge, and the effort to link intellectual discovery more closely to applications has major implications for economies around the world. Universities are key to this effort.

Let me conclude by pointing out that in the United States, the nation's most distinguished research universities are members of an organization called the Association of American Universities. The AAU includes 62 universities——not a large number in comparison with the 3,700 institutions that make up the American higher education system. (It should be noted that six of the AAU institutions are campuses of the University of California.) But, for reasons I have explored in this paper,

these 62 institutions have an impact on America's prospects far out of proportion to their numbers. In a world in which scientific knowledge doubles every 12 to 15 years, research universities are clearly an important element in any nation's economic strategy. And impressive as their past accomplishments have been, the possibilities are so plentiful, and the potential is so enormous, that the most exciting days for research universities lie not behind us but ahead.

Plenary Session II: Human Resources for Science and Engineering

Commentary

Gerald T. KEUSCH*

Session II was devoted to human resources for Science and Engineering. There were three papers presented. Dr. XUE Lan examined the readiness of the Chinese higher education system to educate the needed highly trained scientists, engineers, innovators, and managers for the new knowledge based economy. To move China ahead in the next century, the Chinese higher education system faces 3 critical challenges: 1) to increase the number of highly trained graduates; 2) to link knowledge generation in the university setting to the applications in the commercial market; 3) to provide the continuing education needed in a fast moving society continuously generating new knowledge.

He pointed out several issues of concern about the readiness and capacity of the Chinese higher education system to meet these challenges. First, limited autonomy of the universities from central government control. Second, limited capacity in the universities, which has a per capita enrollment rate and percentage of the total population over 25 years with higher education resembling the poorest tier of countries, and far lower than that of the highly technical industrialized nations. Hence, there is significant imbalance in the supply and demand for such highly educated Chinese graduates. This results in a third problem as high school education increasingly becomes preparation for university entrance examinations rather than focused on education and the Government mandates increases in admissions without consideration of the ability and capacity of the universities to provide quality education. Fourth, universities do not necessarily train graduates in the fields needed by the new economy. Fifth, there is insufficient Government support to pay the costs of quality higher education and Government imposed limits on tuition precludes this as a source to narrow the gap.

Therefore, reform is urgently required if the Chinese higher education system is to become capable of reorienting education to the output-demand needs of a knowledge based economy. To accomplish this will necessitate autonomy of the universities in several spheres, including academic programs and curriculum, administration, and fiscal matters. Attention will need to be directed to the education of a managerial group. Quality of education will need to be insured by development of stan-

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dards and accreditation procedures. And of major importance, private universities will need to be encouraged, including universities with international linkages.

In the second paper, Dr. Richard ATKINSON provided a historical view of the development of the academic base for the new economy in the United States as a way of identifying possible themes the Chinese system could consider. He noted that theory had grown up around performance in the United States, resulting in a “new growth theory” which related investments in R&D to economic growth and identified the important role of Government supported research in the universities in driving this relationship. Federally supported research carried out in the universities has catalyzed private investment in R&D, leading to the creation of new jobs and industry near the universities producing highly trained graduates. Well educated young technologically advanced graduates willing to take risks are available for the innovative, small, entrepreneurial high tech companies that spring up when other local conditions such as the availability of venture capital, and accounting and legal services are favorable. However, it is important to note that universities can play a proactive role in creating this environment—not only in providing the well educated graduates, but also in facilitating technology transfer to industry through programs intended to link the knowledge generation in the universities to business opportunities. Government policy can facilitate this, as for example the laws in the U. S. that gave patent and licensing rights for inventions supported by Federal funds to the universities.

It is interesting to note that Government support of basic research in the universities began to increase in the years following the second World War. American industry was spared the devastation suffered by Europe and Asia, and in fact was in high gear because of the high levels of wartime production. The returning veterans were also provided with financial resources and opportunities to enter higher education, forever changing the perception of university level training as something for the few and elite to something all in the U. S. could aspire to. Education was the key to advancement. The congruence of these factors at the same time in U. S. history appears to have been a critical feature. In addition, certain decisions were taken regarding the administration of process for research. The success of the system in the U. S. can certainly be traced to Government funding of basic research in the universities, however, the emphasis on investigator initiated research proposals and the peer review system in which peer working scientists judge the merit of proposals for funding are essential for promoting creativity and quality. The process is a continuous competitive one in which merit, innovation, and relevance remain the major criteria for support. The guiding principle here of most relevance to China is the recognition in the U. S. that the “universities are priceless sources of ideas that can create jobs, give birth to new industries, and stimulate productivity growth”, although how this principle is applied may differ between the U. S. and China.

The third presentation, by Dr. CAO Zhijiang, traced the history of Legend as one model of this process for China. Legend was founded in 1984 by 11 technically trained members of the Institute of Computer Technology, with “venture capital” from the Chinese Academy of Science. Their first product, a Chinese character processing system, was versatile and useful. A decision was made to

tailor the product to the non-professional PC user, a market that did not exist in China at the time, rather than mainframe computer needs. The wisdom of this decision can easily be seen in retrospect, as Legend has surged ahead in sales and market share in China and the rest of Asia. Several principles of business were promoted that have permitted this rapid growth: 1) product development and marketing were closely coordinated; 2) after sales service was geared to customer support; 3) technical staff engaged customers and learned first hand of customer needs so that product improvement was continuous and geared to the market. The continuing orientation of Legend to integrate high tech R&D to the market is reflected in its allocation of its R&D budget, with 20% devoted to basic research, 30% to key technology research, and 50% to application research for the development of new high tech products.

The personal computer industry is a good example of the possibilities of well organized R&D tailored to marketable products, as sales have taken off all over the world, and at the same time it may be one that is difficult to replicate with such speed and success in other industries. In China, the further maturation of Legend to a public company, owned in part by its employees, is another striking change from the former State Owned Enterprise model, and very much in line with the situation in the U. S. and other highly technical industrialized societies.

In the discussion, several themes emerged: First, there is great potential in distance learning methods for high tech education, between the US and China, for example, or from technically advanced, research intensive universities to students elsewhere within China. This is applicable to the didactic components of biomedical research training, including clinical research methodology, clinical trials, and clinical data collecting. Some of this can be accomplished by internet, teleconferencing and other electronic communication modalities.

Second, peer level training, both national and international, can be a highly effective mechanism for information transfer, supplementing the senior mentor: trainee interaction in a less formal environment. Hence, opportunities for US trainees to work in China alongside Chinese trainees should be fostered, in addition to enhancing the opportunities for Chinese students to train in US institutions. Relationships developed during training are often sustained lifelong, and are the basis for establishing and sustaining close and trusting research collaborations.

Third, research training must be carried out in the course of conducting research, wherein methodological tools are applied to the solution of research questions. The opportunity to link theory with practice in the solution of real problems is essential. In the course of developing undergraduate, graduate and post-graduate research training, there must be sufficient resources to carry the burden of frequent experimental failures, and resources to allow trainees to problem solve to get beyond the barriers. Without this there can be but little progress. At the same time, it is necessary to establish some peer review process to review the productivity of training laboratories and centers. In the US, this is accomplished by the need to renew Federally supported research grants through the competitive peer review process for grants for both research and training.

Parallel Breakout Session, Part II: Human Resources Development

Knowledge-based Economy and Human Resources Mobility —The Practice of Postdoctoral System in China

CHEN Hao and LIU Minhui*

Abstract: Mobility of human resources is very important to develop the knowledge-based economy. This paper introduces the practice of China's postdoctoral system to discuss the relationship of the knowledge-based economy and human resources mobility. CAS's postdoctoral program is introduced as a typical example. Future development of China's postdoctoral system and attention to improving it are also discussed in this paper.

1 KNOWLEDGE-BASED ECONOMY AND HUMAN RESOURCES MOBILITY

1.1 In Essence, the Knowledge-based Economy is the Talent Economy

We are stepping into a society of the knowledge-based economy. In this kind of society, knowledge is the most important power driving the economy. With knowledge being the core of the knowledge-based economy, human resources become far more important than before. Human resources have been treated as necessary to the economy for a long time. But because of its extremely important role in the knowledge-based economy, producing, spreading and utilizing knowledge, human resources are not only a necessary element but also a prior element now, which means that they should be developed prior to other elements such as capital, facilities and so on. Humans drive knowledge and knowledge drives the economy.

In the knowledge-based economy, not common workers, but knowledge workers contribute giant energy to the development of the economy. It is high-level S&T talent that make human resources such an important role in the knowledge-based economy. They are knowledge workers of the new kind of economy. High-grade engineers, professors in universities, researchers in academic insti-

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tutes produce a mass of S&T knowledge and turn it into actual productivity. They spread and use knowledge to produce both consumer goods and more new knowledge. It is their work that leads and pushes the development of the economy. High-level S&T talent is critically important to the development of the knowledge-based economy. The knowledge-based economy is essentially a talent economy.

1.2 Mobility of human resources is one of the essential characteristics of the knowledge-based economy

In the knowledge-based economy, knowledge needs to be transferred quickly to produce and utilize knowledge efficiently for people. This is the fluidity of knowledge. To adapt to the fluidity of knowledge, human resources need to be mobile. When talent moves from one place to another, knowledge transfers with it. When researchers with different backgrounds form new research groups, creative new scientific attainments are easier to achieve. When professors in universities and researchers in institutes move to factories, new consumer products appear and are produced more efficiently. Talent also becomes more qualified through the flow among different places. Mobility of human resources is very important. With mobility, an efficient high-level S&T talent management system is necessary. The system should be able to keep up the quality of talent resources and be propitious for knowledge workers to produce, spread and utilize knowledge while talent is dominated by market power.

1.3 China Needs an Innovation of Its High-level S&T Talents Flow System

China's economy is far from the developed knowledge-based economy. But it is also stepping into this kind of economy with more and more tight relationships with developed countries. Compared with other countries, China faces more difficulties to succeed in this kind of economy. The long-term traditional planning economies have formed an inefficient talent resources utilizing and management system in China. Young people are selected into colleges and universities, and are pointed to certain work positions according to the government's plans when they graduate. Many governmental rules are made to limit their mobility. Lots of people can only work in one place for their whole lives. This kind of system once contributed much to the development of China's economy, but now it becomes more and more inappropriate. The system limited the mobility of talent and limited their enthusiasm and creativity at the same time. Millions of bachelors, tens of thousand of masters and thousands of doctors graduate from universities every year in China. But they haven't played the role they should have played in developing the nation's economy. The prime reason is limited mobility. Talented people are limited to certain provinces, to certain cities, to certain universities, to certain factories and even to certain positions. This situation inhibits talented people to form creative groups and to be utilized efficiently. It is a costly waste to the state. The government invests much but gains little. Limitations on talents leads to limitations to producing, spreading and utilizing knowledge. The knowledge-based economy is nonsensical in this kind of system. To change this kind of situation, some new efficient talent management systems are needed. The post-

doctoral system is one such new systems.

2 THE POSTDOCTORAL SYSTEM IS AN INNOVATION OF CHINA'S TALENT MANAGEMENT SYSTEM.

The postdoctoral system has existed in some countries for a very long time. But it is new for China. It was introduced into China 14 years ago. It has many functions: protecting talent resources, enhancing science research exchanges and so on. It has two essential characteristics: (1) The postdoctoral position is temporary; (2) Postdoctoral researchers possess high-level S&T talent. These two make this system an innovation of Chinese high-level S&T talent management system.

First, limitations of present resident registering system to high-degree talent is broken. In China, the government stipulates that postdoctoral researchers can choose places to work and dwell with their wives and their children freely outside of limitations of the present resident registering system and local governments' policies.

Second, the lifetime employing system is broken. Because the postdoctoral program is a two years long temporary research period, employers and postdoctoral researchers can understand and adapt to each other during this two years. Further employment will be determined by both the employer and the postdoctoral researcher. Job contracts are also used to regulate the process and protect both sides.

Third, the phenomenon of in breeding in academia is reduced in some degree. In China, young PhDs are forbidden to attend postdoctoral programs of universities or institutes where they got their doctor degrees. The mobility of talent leads to exchanges of academic attainments and academic ideas.

Fourth, the postdoctoral system can enable high-level S&T talent to stay in a continuing academic circumstance. For young doctors who just graduate from universities or come back from abroad but can not find a suitable job, the postdoctoral system provides them a temporary position to continue their professional research work without regulations of impersonal conditions.

The number of postdoctoral mobile stations has increased from 102 in 1985 to 787 in 1998 in China. The postdoctoral system is being improved from then on. It has been an important innovation of China's talent resources management system. It not only has positive effects on improving the development of Chinese scientific research but also greatly influences the reformation of the nation's other systems.

3 THE PRACTICE OF THE POSTDOCTORAL SYSTEM IN CAS

The Chinese Academy of Sciences is one of the most important research bases of China. Its postdoctoral program provides a good overview of China's postdoctoral system. In 1985, at the beginning of the postdoctoral system in China, CAS was permitted to establish the first set of postdoctoral mobile stations. In the past 14 years, the postdoctoral system in CAS has become more and more important in selecting and cultivating high-level professional researchers, enhancing the mobility of talent and attracting overseas researchers. It also has had impacts on promoting academic exchanges and cooperation among different academic disciplines, expanding research areas, developing new research fields, and enhancing scientific research work.

3.1 Introduction

In 1984, the Institute of Theoretical Physics and the Institute of High Energy Physics tried the postdoctoral program in China first. Three postdoctoral researchers were admitted. In 1985, 102 postdoctoral mobile stations in 73 universities and institutes throughout the country were ratified according to comments of the National S&T Council, the Ministry of Human Management and the National Postdoctoral Mobile Station Management Council. 36 stations, 37.3% of all postdoctoral mobile stations, were established in CAS. By the end of 1998, there were 102 postdoctoral mobile stations in 82 institutes of CAS, 12.9% of the total 787 mobile stations of the country. CAS has admitted 2248 postdoctoral researchers since 1985, including 265 overseas researchers. By the end of 1998, 1329 researchers have finished their postdoctoral programs in CAS.

Leaders of CAS place importance on postdoctoral programs. One million RMB Yuan was invested into these programs as special postdoctoral spending each year since 1985. The amount of money has been increased to two million Yuan since 1996. Most of the money was granted for post doctors' daily living expenses.

3.2 Effects of Postdoctoral Programs in CAS

3.2.1 The postdoctoral program has become an effective way to cultivate and select high-level S&T talent

Postdoctoral researchers are selected from preeminent young doctors who have just got their degrees from domestic or foreign universities and institutes. Before they get long term research positions, postdoctoral mobile stations can provide them an environment with high level academic circumstances and a chance to carry out research work independently in competitive academic circumstances. Most institutes that are allowed to establish postdoctoral mobile stations in CAS have state laboratories or CAS open laboratories. There are famous scientists, advanced research equipment and favorable research circumstances in these institutes. Postdoctoral mobile stations help young researchers to solve lots of daily problems so that they can concentrate all their energies into research

work. The practice has demonstrated that the postdoctoral system is an effective way to cultivate and select preeminent S&T talent. Many young scientists have become leaders of academic research programs through the postdoctoral program. The research group of CAS is also greatly strengthened.

3. 2. 2 A series of important scientific attainments have been acquired

Most post doctors have strong abilities to carry out research work independently with well-knit fundamental professional knowledge. They have active academic ideas and dare to innovate. Most of them can acquire fairly high-level scientific attainments during their two years postdoctoral periods. They have become an indispensable fresh strength to develop the academic research work of CAS.

3. 2. 3 The postdoctoral system has promoted academic exchanges and the cross fertilization of research fields

Some post doctors come from domestic universities and institutes, and some come from foreign universities. There are also a few foreign researchers. They bring different academic ideas, different work styles and different research methods. Research fields are broadened and some new academic areas appear. These post doctors with different backgrounds work together with long term researchers, discussing academic problems and exchanging research experiences, which greatly promotes the development of scientific research and the spread and use of knowledge.

3. 2. 4 The postdoctoral system attract preeminent talent, promotes the mobility of talent and deepens the reformation of talent management system

The postdoctoral system provides young researchers fair competing opportunities. Government provides a series of preferential policies for the postdoctoral system so that CAS can provide post doctors better conditions than those of who haven't attended the postdoctoral program. CAS's powerful research ability and high international academic fame attract lots of preeminent young doctors. Many CAS institutes sited in back lands can attract qualified young researchers by the postdoctoral program.

The practice of past years shows that the postdoctoral system has enhanced the reformation of the talent resources management system in CAS. The efficient mobility of high-level S&T talent is realized through this system. It is also an effective way to improve the structure of the research groups in CAS.

3. 3 Important Experiences

Management and organization are very important to improve the development of the postdoctoral system. In the past 14 years, institutes have acquired some useful experiences to manage talent

through practice.

3.3.1 Attitudes of leaders and cooperation of relative units are very important.

Leaders' attitudes are critical to the work. In the process of establishing the postdoctoral system of CAS, institute leaders treated it as a strategic measure determining the institute's fate. They prepare by applying materials, provide favorable research conditions for post doctors and selecting qualified post doctor candidates with great enthusiasm. The postdoctoral program is also a systemic work. Management departments, laboratories, living service departments and other units need to cooperate closely.

3.3.2 Candidates should be selected carefully and their research work should be examined strictly during the postdoctoral program period.

In recent years, the number of applicants is increasing year by year. The ratio of applicants to these selected ones is 4 to 1 on average. It is even more than 10 to 1 in some institutes. This kind of situation is favorable for institutes to acquire their preferred candidates. To ensure the quality of applicants admitted, many institutes develop a series of effective methods. They determine their admission plans yearly according to the number of their research programs and the need of the development of their institutes' distinct research fields. Candidates are evaluated carefully in aspects of professional favorites, research abilities, past scientific attainments and personnel characteristics by a special expert council. Some institutes require post doctors to take at least one academic lecture at the institute's academic meetings. Some institutes ask them to report their attainments to a special academic council at the middle of their research periods. Serious final comments on post doctors' research work are made. These strict requirements encourage postdoctoral researchers to take full advantage of the two years and try their best in research. The effective controlling system accelerates the appearance of high-grade scientific attainments.

3.3.3 Postdoctoral mobile stations should provide researchers favorable research environments and comfortable living conditions.

Most post doctors are young people who have decided to devote their whole lives to scientific research work. They are eager to achieve the top of high-grade scientific attainments. It is very important for stations to provide them with favorable research environments. Available living conditions also attract highly-qualified applicants. CAS can not only provide post doctors advanced experimental equipment but also provide them lots of high-qualified cooperating directors of high scientific attainments and strong enterprises. These skilled scientists are enthusiastic about helping young researchers. Postdoctoral mobile stations should try to create opportunities for international academic exchanges for post doctors and encourage post doctors to attend many kinds of academic meetings. To meet the need of research spending, stations ought to help researchers to apply for research funds and encourage them to take part in some momentous state research projects.

4 TO IMPROVE CHINA'S POSTDOCTORAL SYSTEM

The first 10 years of the next century will be a critically important period for China to become a middle-developed country. The economy and S&T will develop rapidly. It is a good chance to develop the postdoctoral system. This system will help the economy in turn. CAS should grasp this historical chance to improve its postdoctoral programs and then strengthen its research groups. This is also true for China as a whole.

4.1 Future Situation of the Postdoctoral System in China

It can be foreseen that China's economy will continue increasing at a high rate from the end of the this century to the beginning of the next century. The rapid development of the economy will lead to the need of lots of high-level S&T talent. At the same, so many old scientists and technologists will retire during this period that talented young scientists will be needed.

This period is also critical for China to survive in the highly competitive world. The average age of high-grade scientists is more than 50 now. Most of them will retire within 10 years. Lots of young scientists, especially the new generation academic leaders with international influences, need to be integrated into research groups. While the transfer of research tasks between two generations of scientists is being realized, the adjustment and optimizing of the structure of the research group will also be very important. The expected structure of research groups should be a few permanent long-term researchers plus in flows of new researchers. The practice of the postdoctoral system in CAS has shown that post doctors are not only an importance source of academic leaders, but also an important component of in flowing researchers.

The postdoctoral system consists of the cultivation, selection and utilizing of talent. It is not only an effective way praised by institutes that have established postdoctoral mobile stations, but is also of great attractiveness for young doctors.

According to the latest investigation of graduating doctors, 42.2% of them are willing to participate in the postdoctoral program. With the development of China's economy, the scale of the education of graduate students, especially doctoral graduates, will continue enlarging. According to the National Education Council's estimation, the number of doctoral graduate students admitted by universities and kinds of institutes will be 10,000-15,000 each year by the end of this century. If this development trend continues, there will be a great increase both of the demand of post doctors and of the supply of postdoctoral applicants. The scale of postdoctoral programs will be enlarged in the future.

4.2 Attention to Improve the Postdoctoral System

4.2.1 Recognizing the critical importance of the postdoctoral system to cultivate talents and to win in future competitions about high-level talent

Experiences of the past 14 years have demonstrated that the postdoctoral system is critically important in cultivating and selecting high-grade academic leaders, optimizing the structure of the research groups and promoting research work. China has to attract more qualified young researchers to its research groups to win the in future's competitions about talents. It can take advantage of the opportunity that scientific research tasks are being transferred between two generations of scientists. The situation is similar to that of CAS.

There is no effective systemic talent management system in China at present. The postdoctoral system is a breakthrough of the old talent management system. Effectively using this system can lead to an effective mobility environment for high-level S&T talent.

4.2.2 Improving the research environment and providing post doctors better living conditions

For young scientist with enterprise, the greatest allure is the favorable research environment that can help them to achieve high-level scientific attainments. Many young doctors choose to participate in the postdoctoral program of CAS because of its high-qualified research teams, advanced experimental equipment, frequent international academic exchanges and active academic circumstance. All of these are advantageous conditions of CAS and allurements for young doctors. But compared with those of foreign universities and institutes, these conditions, both in research and in living, need to be greatly improved.

Converting young doctors into professional researchers during the postdoctoral period by strict training and hard working is the goal both of the institutes and post doctors themselves. Two years is too short for young scientists to acquire important scientific attainments. It is the postdoctoral mobile stations' duty to help post doctors to prepare for their research projects before attending the postdoctoral program and solve many kinds of problems encountered to reduce time delay. In short, to make the postdoctoral mobile station a preferred place for most excellent young doctors, improving post doctors' research environment is necessary, both for CAS and for China.

4.2.3 Establishing a Systemic Management System

The practice of successful examples shows that a systemic and scientific management system is very important to the postdoctoral system. When the scale of postdoctoral programs is enlarged, management work becomes more important.

Some institutes have established effective methods and procedures to select qualified applicants and

check post doctors' research work. These procedures should be integrated into the whole system so that the postdoctoral program can be carried out and managed efficiently under clear rules. Post doctors are neither students nor 'high-grade labors' of institutes. They are young scientists with strict academic training and doctor degree. Compared with students, they are professional researchers. Compared with institutes' long-term researchers, they are young and mobile. They have strong creative abilities. To get the utmost out of their creativity, institutes must be respectful of their research preferences. Within the integral planning, post doctors should be permitted to choose their research subjects as freely as possible. They also should be encouraged to carry out research work independently to acquire experiences by practice.

To stimulate post doctors' activities, some incentive systems are necessary. CAS has established special postdoctoral funds to support and reward excellent post doctors. Those postdoctoral researchers with poor achievements are subjected heavy pressure and even may be advised to quit the program.

5 CONCLUSION

In essence, the knowledge-based economy is a talent economy. Human resources are of critical importance to the development of the economy. The mobility of human resources is one of the essential characteristics of the of knowledge-based economy. High-level S&T talent are knowledge workers of the knowledge-based economy. To realize the mobility of human resources, an efficient high-level S&T talent management system is necessary. China has been under a planning economies for a long time. This kind of system is very harmful in the knowledge-based economy. To solve the problem, the postdoctoral system was introduced. Two essential characteristics: (1) The postdoctoral position is temporary; (2) Postdoctoral researchers are high-level S&T talent, make this system an innovation for Chinese high-level S&T talent management system. CAS's practice is typical in China. The practice of the past 14 years has shown that the postdoctoral system is positive for China. Experiences from past practice are very useful. The scale of China's postdoctoral system will enlarge in the future. Important attentions should be paid to factors to improve China's postdoctoral system. The first 10 years of the next century will be the critically important period for China to become a middling-developed country. the economy and S&T will develop rapidly. It will be good chance to develop the postdoctoral system. This system will help the economy in turn. China should grasp this historical chance to improve its postdoctoral system and step into the knowledge-based economy.

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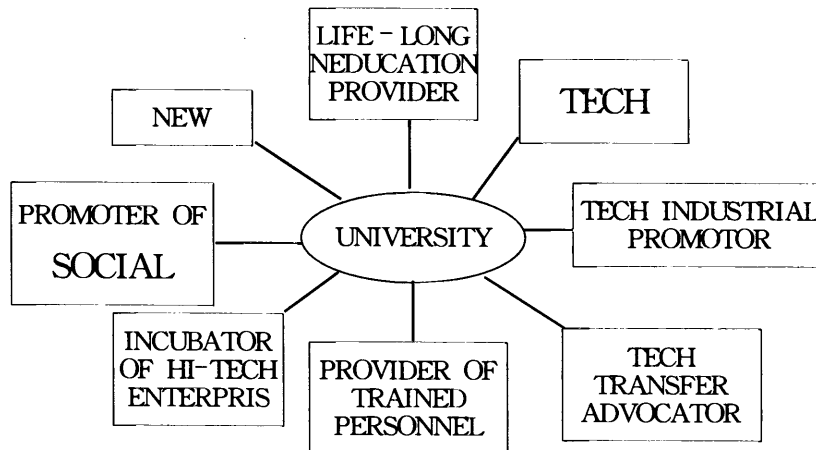
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University Role in Regional Development

CHU Xuelin and LI Hongyan *

Abstract: Chinese universities have been actively exploring the roles they should and could play in regional economic development. As a researcher on technology management and an active member of the University of Science and Technology of China, the author conducted careful and critical observations, and concluded that with their obvious superiority in science, technology and personnel, universities assume irreplaceable position in regional economic development. Eight major roles were identified, namely new knowledge generator, lifelong education provider, technology transfer advocator, technology industrialization promoter, technical information disseminator, promoter of social development, incubator of hi-tech enterprises, provider of trained personnel. It is also advocated also that these roles would undergo changes in form and manner in the knowledge economy that is emerging.



1 Background

Information technology is a remarkable product of the 20th century. New and high technology will further develop in the next century, leading to big leaps forward for society. At the turn of the century, Chinese universities are exploring the ways and roles of the university in regional economic development. Enterprises and government are also interested in how to give full play to the functions

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of universities in regional economic development.

It is well recognized that high technology has generated great impacts to social and economic development, in its direction, nature and speed. As a wise Chinese politician, Deng Xiaoping advocated that science and technology is the number one productive force. Thereafter, Chinese governments at all levels formulated a new economic development policy: "to be prosperous, rely on science, technology and education".

The American scholar, Dr. Kotzmensky has listed seven factors influencing regional economic development. These are new channels, infrastructure, entrepreneurship, trade and export, value-added manufacturing, creative environment, and education. These have been demonstrated by the historical development made by Hong Kong, Taiwan, Singapore, Korea, the USA, and Germany. More cases could be listed. Another American scholar Rostole has pointed out that "development means to uninterruptedly and effectively introduce new technology into the economy."

All these ideas make it worthwhile to re-think about the roles of universities in the economic development of a region.

2 University Role in Economic Development

Silicon Valley and Highway No. 128 in the USA have created a new model for regional development, which has attracted worldwide attention. Various kinds of economic, technology development zones have been formed centers around universities. Austin (USA), Xinzuo (Taiwan), Kent Ridge (Singapore), Zhongguancun (China) have become popular names known for their accelerated growth. They have set examples for other regions.

The experiences of 53 high-tech parks in China are also centered around universities and research institutes. Research achievements, talented personnel, and spin-off companies from universities have contributed greatly to these region's growth and development. Based on the above observations, we can conclude that universities have become the driving force in the social and economic development of these zones.

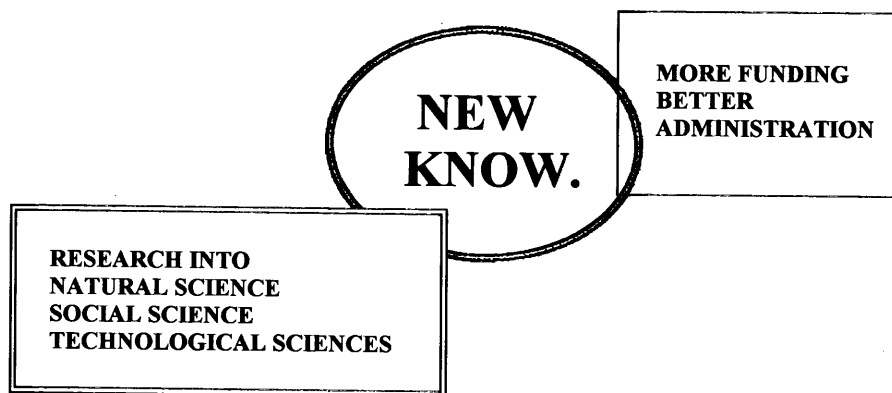
In the recent discussions on the knowledge economy, it is noted that industrialization of high technology will lead to a completely new economic style. This makes it necessary and meaningful to re-consider the roles of the university in regional economic development in the future.

2.1 Knowledge generator

Universities, research universities more precisely, are by tradition the key players for scientific research. Their scientific achievements have contributed to the knowledge body of mankind. According to research on high education systems, the exploration of truth, creation and innovation are the

basic functions of a university. Universities provide the theoretical backup for high technology and social development through education, disseminating new technology, new scientific thinking and technical methods. In the future, the university will no doubt continue to play such role in society.

Statistics has shown that in major research universities basic research projects consist of well over 60% of the total. The university of Science and Technology of China (USTC), as an example, has adopted new policies in recent years to reorganize its ranks for basic research to consolidate its ability to follow academic development. Looking into the future, more funding and better administration are needed to facilitate such a role.



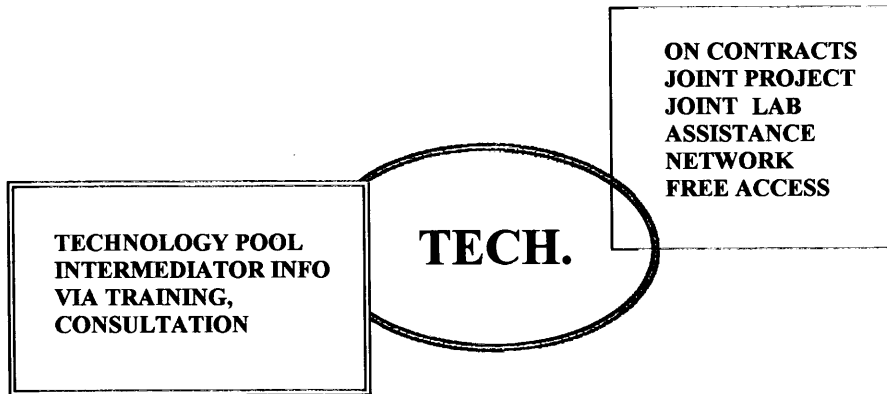
2.2 Technology information disseminator

In addition to knowledge generation, universities also function as an important disseminator of new technology, as they possess multi-disciplinary personnel and a network environment. They assume the source of new technology through many different ways, namely technology development through contracts, joint-development, training, joint institutes, and so forth. Technology is transferred to other members of society through direct selling, education-production-research cooperation, and technology popularization.

It is worth noting that universities possess a large technology pool, high technology capability, language ability, and mixed technical personnel, compared with most enterprises. Therefore, whenever there is a technical problem to be tackled, managers of firms and government administrators naturally turn to universities to seek help and assistance. They become strong backup forces to assist firms to identify, understand, and digest new technology. Having developed up-to-date computer networks, universities quickly become channels for current information. Actually, university acts as agent or intermediary for new technology and information.

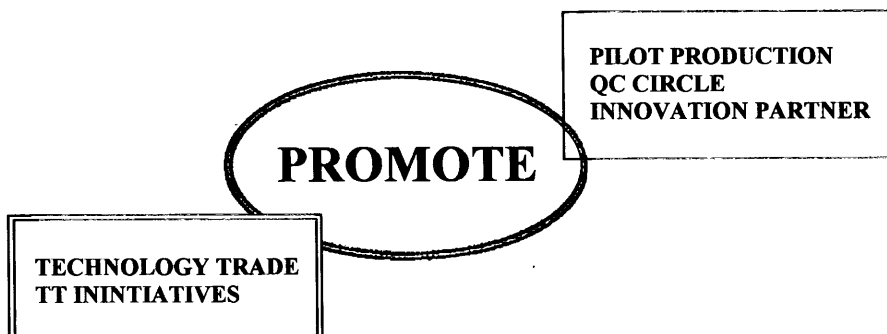
It can be expected that we will see more on contract development projects, joint projects and joint

labs on the university campus. To further promote this role, better computer networks and social networks are important. Low cost or more ideally free access to university resources would be beneficial to societal development.



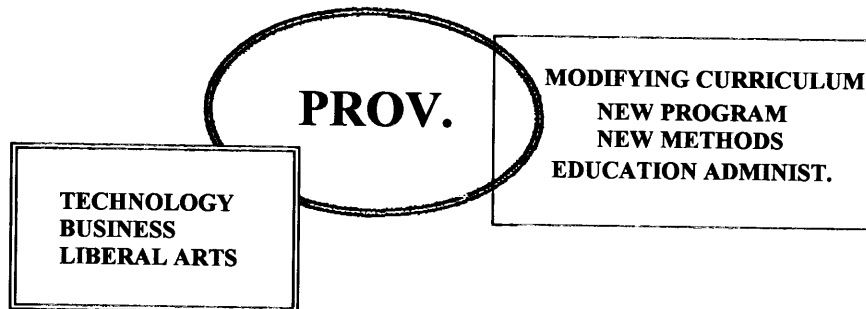
2.3 Promoter of technology transfer

Understanding its important role in technology advancement, universities are modifying or re-formulating policies to promote technology transfer. They encourage teachers and students to transfer technology into products, start education-research-production (E-R-P) joint projects, and set up pilot production facilities. University technicians are major players in the technology market and technology trading in most areas in China. They directly provide technology, sell and provide consultation to company end-users, and thus speed up the transfer and application of new technology. Good cooperative working relations have been built between universities and enterprises. Now it is common to see joint laboratories on campus co-funded and jointly-operated by university and company. For the future, we might suggest that they should increase their ability in pilot production. To form partnership in innovation process or QC circles with companies will help to promote technology transfer.



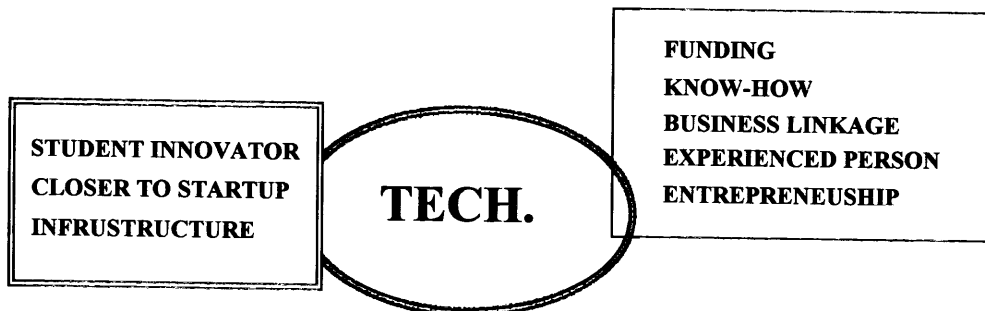
2.4 Provider of technical and management personnel

Preparation of technical and managerial personnel is another basic function of universities. To do it better, universities are adjusting and modifying their curriculum design to catch up with technology advancement. Most firms depend on universities to provide the trained work force and managers who are well equipped with up-to-date management knowledge and skills.



2.5 Incubator for technology-based business

As university students and teachers are major groups for technology innovation, university-run incubators have superiority abilities to meet the needs of start-up technical firms. Assistance to them includes hardware infrastructure and business know-how. Studies show that most university-run incubators are non-profit in nature. They play an important part in promoting entrepreneurship and economic development. For better development, funding, business know-how, and business link-

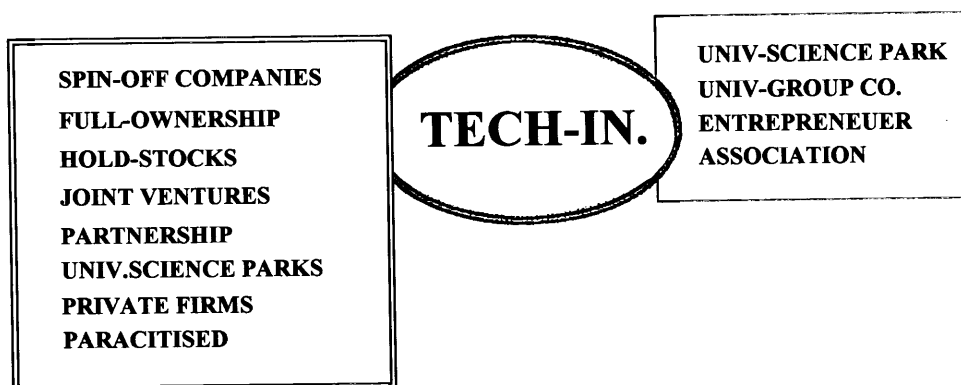


age are essential.

2.6 Promoter of technology-based industry

Universities have superiority in technology and personnel, and could play different roles in starting

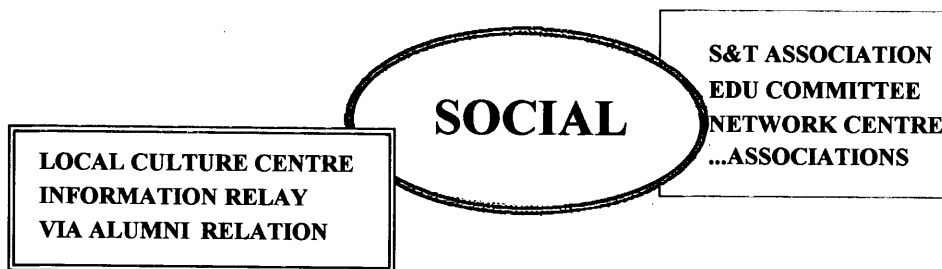
technology concentrated industry. Spin-off companies, full-ownership companies, hold-stocks, joint ventures, partnership are just a few ways for universities to get into technology industrialization. In recent years, a new development is for universities to start their own science parks. Such parks would serve as an internship base for students, are good for linking the university with society, and to promote service. It is also considered good for transforming the educational system. In terms of social effects, university-run enterprises in China have generated reasonable economic results to contribute to the development of the university. In the geographical surrounding of an active research university, we find large groups of private firms taking shape, making use of the technology and personnel of the university. We should see more university science parks in the future. But it is expected that they will not be separated from but more closely linked with outside companies.



2.7 Promoter of social development

Research has indicated that in the dissemination process of technology, information communication plays an important role. It is also worth mentioning that information relays would be more effective via grapevine communication channels. It is interest to find out that the alumni relation existing among graduates from the same university is such a useful or functional chain, which helps to break through many organizational barriers. Similar channels could be found among classmates, student-teacher, and relatives. It is not strange to find that all kinds of alumni activities contribute to regional development.

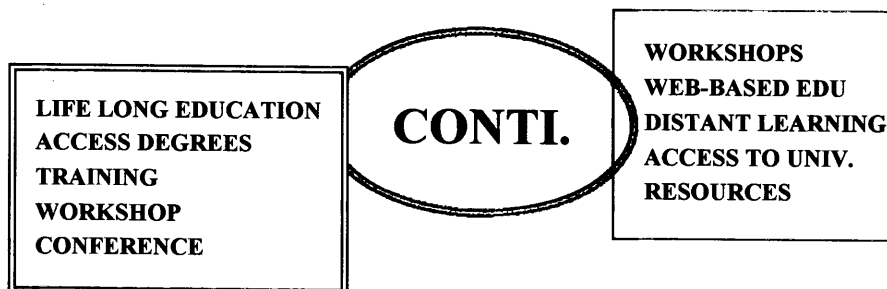
To give it a full play, training and seminars organized or hosted by universities help to bring people together to share technology, business and management information and experiences. And these are of course useful for more active development actions. Owing to such reasons, one finds that many cities in the world grow-up around a university and prosper. Examples are Austin with the University of Texas(UT), Cornell in Ithaca, New York, and Xinzuo in Taiwan with Jiaotong University. In stead of industrial parks, we see city development around universities.



2.8 Centers for continuous education

The emerging knowledge economy has made us to think about how to improve the creativity of people. It is common understanding now that people need life long education. Today, universities have greatly expanded their offerings in general education to include degree programs, diploma program, training, and other educational services for society.

In the era of fast development of science and technology, the obsolescence rate of knowledge is increasing, and technicians need to learn new skills to keep a breast of developments. Back to school has become a common choice. Universities can and should provide support both in instruction and facilities. Experiences have indicated that seminars, training, workshops, and conferences hosted by universities are effective approaches. The emerging network-based learning environment will also provide convenient methods. Universities can play a bigger and better role in this direction.



3 Further thoughts on the roles of university

Universities need to address these challenges to play their roles better in regional economic development.

3.1 Mode for development

Since the university plays multiple roles in regional development, the operation mode of the university needs further consideration. Whether to keep it as technology pushing or market driven, an open system or societal. Each has its own advantages and limitations.

3.2 Campus culture to support technology development

Obviously, basic research and technology development have different objectives. And Contradictions and conflicts should be expected. The new campus culture should accommodate both for their healthy development.

3.3 Technology integration and transfer

New technologies are developed by integrating mutual supporting technologies. How will it be possible to overcome common weakness of the university in lacking pilot production facilities, production skill and know-how? It seems that the solution is to cooperate with firms by joint development efforts.

3.4 Financial support

The development of a modern university requires large investments. Though government can provide more funding, this will be limited. Multiple investment channels are the best way to solve this problem.

3.5 Prepare a new generation of entrepreneurs

The new economy type needs personnel with a new composite of knowledge and skill. Universities should adjust their largely traditional way of preparing personnel. Creativity, entrepreneurship, practical skills, and problem-solving ability are all needed. Universities should find new modes for personnel training.

To respond to the above issues demands more study and experimentation. These are the task for professors and administrators of universities.

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Preparing Scientists and Engineers for the 21st Century

Edward Alton PARRISH*

Overview

- 1 Background
- 2 Knowledge-Based Economy
- 3 Educational Challenges
- 4 WPI's Approach
- 5 Conclusions

1 Background

To establish context, let's consider some disruptive technologies that have affected global societies.

Disruptive Technologies

- Railroads
- Telephone
- Internal Combustion Engine
- Electric Power
- Mass Communications
- Jet Travel
- Plastics
- Microelectronics
- Internet

Last 150 years or so has seen many disruptive technologies appear.

- Telephone was perhaps the greatest breakthrough in IT ever.
- Electric power was also an enabling technology, making every part of the economy more efficient.
- Microelectronics forever changed IT and consumer products, and led to the Internet revolution.

Now look at impact on knowledge transfer and innovation.

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2 Knowledge Transfer and Innovation

Late 1800's saw railroads and telegraph speed up rate of technology diffusion.

20th century saw telephones and air travel increase rate of technology diffusion more.

1980's still had national economic borders so that innovation took about 10 years to transfer between countries.

Now in Internet time.

Internet effect more profound than that of railroads or electricity; traditional factors of production——capital and skilled labor——are giving way to the ability to control and manipulate information (knowledge) as the determinant of the power of an economy. What can we expect in the future?

21st Century Context

- Dramatic growth of information (computer) and communication technologies.
- Efficient global transportation systems.
- Recognition of limited natural resources and adverse environmental effects.
- Diminishing effects of location due to *virtual* 24×7 workplaces and marketplaces.
- Increasing globalization affecting industry, academia, and governments.

What will these lead to?

Likely New Global Market Demands

- Mass production of customized products and services.
- Relentless pressure for lower costs and higher quality.
- Revolutionary reductions in product cycle times.
- Sustained advances in IT, miniaturization, computation and simulation, materials, etc.

What might companies do in response?

- Example Response to Demands
- Today's assembly lines are geared to producing standard models.
- It takes weeks to turn out customized vehicles
- e-GM Goal:
- Customer configures vehicle over Internet.
- Climbs behind wheel in days.

What about the new knowledge-based economy?

Knowledge Based Economy

- Based upon intellectual assets, not physical assets or location.
- Primary competitive advantage will be an organization's ability to *learn* and to *innovate*.

-Enabling technology will be an organization's ability to *manage knowledge* and its employees abilities for *continuous learning*.

Knowledge Management: getting the right information to the right people at the right time so they can take action and create knowledge with value.

Biggest challenge for knowledge management is not IT, but culture as employees are competitive by nature and tend to hoard rather than share knowledge.

Another challenge is ensuring technical staff remain current.

Continuous Learning is New Paradigm

The new economy is heavy on intellectual capital. The sharing of knowledge is what really makes it go.

People should expect lifelong learning, not necessarily lifelong employment.

Moving from lifelong employment is a major paradigm shift affecting many countries, including US and Japan, for example.

Since knowledge is so important what are its characteristics?

Characteristics of Knowledge

Defies traditional economics of scarcity—using it doesn't consume or deplete it—economics of abundance.

May be shared without giving it up.

May increase with use and sharing.

Pricing and value depends on context.

Has higher value when in repository than when it can "walk out the door" in people's heads (knowledge management).

What kinds of knowledge are we concerned with?

Datamining: accumulate data; do correlations to determine patterns in data to get information; convert to knowledge by hypothesizing situation.

Data: any set of measurements, facts, figures without context.

Information: statement of fact about data.

Knowledge: actionable or processed information.

Innovation: transformation of knowledge into new products, processes, or services.

Kinds of Knowledge

- Explicit
- Contained in manuals and procedures.
- Easy to teach and to transfer.
- Tacit
- Know-how learned through experience.
- Hard to teach and to transfer (indirectly through metaphor and analogy).

Creation of this tacit knowledge or know-how depends on education and research.

How did Japan take away US markets for automobiles and electronics? US managers focused on explicit knowledge while Japanese counterparts focused on tacit. The key to Japan's success was the ability to convert tacit to explicit knowledge.

Conversion example is Matsushita's automatic bread machine. Designers couldn't perfect kneading mechanism; programmer apprenticed with master baker at Osaka International Hotel, gained an understanding of kneading, and conveyed information to engineer, thereby converting tacit to explicit knowledge.

What educational issues can be derived from all this?

3 Educational Issues

Transition from Industrial Age to Knowledge Age and economy requires:

- Universities become learning organizations as well as learning centers (rather than teaching centers).
- Broad undergraduate education—"new" liberal arts.
- Innovation demands collaboration.
- Historically, schools encouraged individual competition.
- New infrastructure needed to support teamwork.
- New culture needed for knowledge management—requires willingness to share.

How might this affect our teaching methods?

Changing Pedagogy

Traditional

- Teacher Centric
- Single Medium
- Individual Work
- Passive Learning
- Artificial Context

Future

- Student Centric
- Multimedia
- Collaborative Work
- Active Learning
- Real Problems

How are accreditation agencies influencing education? Consider an example:

Role of Accreditation

- ABET accredits all engineering programs in US, substantial equivalency of international programs.
- Changed criteria from educational process to *outcomes* basis
- Requires outcomes be balanced between technical and life skills
- Promotes program flexibility

Breaks cookie cutter and allows great flexibility for engineering programs to set own objectives subject to a floor that sets standards for what it means to be an engineer.

Let's look at these outcomes.

Desired Educational Outcomes

- Fundamentals and necessary technical depth.
- Life Skills——communicate effectively, teamwork, leadership, impact of technology on society, ethics, global perspective.
- Sustainable lifelong learning skills.
- Experience both explicit and tacit knowledge transfer——learning outside classroom.
- Learning to learn cannot be taught in classroom; learn by doing.

What are the underlying implications?

Implications for Technological Education

- Technological education should produce generalists (breadth) at undergraduate level.
- Provide undergraduates with opportunities to gain global experience working in teams in situ.
- Leave detailed specialization (depth) for graduate studies.
- Information technology fully leveraged.
- Meet needs for lifelong learning.

Most US efforts at global experience aimed at graduate students or traditional university undergraduate exchange programs. Undergraduates are more malleable and impressionable, so global work-like experiences more valuable at earlier age.

IT for multimedia support for adaptive learning environments.

Learning no longer ends with formal programs leading to degrees, but must continue throughout careers. Means institutions have responsibilities beyond students' graduations.

Look at what is happening in US

-Lifelong Learning in US

-Adult education reached 23 million Americans in 1984, 76 million in 1995, and may exceed 100 million by 2004.

-Business needs brought growth in corporate universities;
400 in 1988 and 1600+ today.

Example corporate universities: GE, Motorola, Unisys, FedEx.

Also are seeing the rise of virtual universities to meet demands.

Potential for Distance Learning with Internet

4 WPI's Approach

Faculty saw changes coming 30 years ago.

Moved from traditional to project-based programs.

Eliminated prescribed sequences and prerequisites-individually tailored programs.

Focused on outcomes-mastering subjects rather than passing specific courses.

Discuss one university's approach to meeting these challenges.

Learning Centered

-Experiential—learn by doing.

-Three major projects required for all students;

-Sufficiency.

-Interactive Qualifying Project.

-Major Qualifying Project.

-Significant learning outside classroom.

-Oral and written reports to sponsors.

-Moved from teaching centered to learning centered in its approach.

-Teams of 3—4 students working with faculty advisor.

Required changes in infrastructure

-Revised Infrastructure

-Four 7-week terms.

-Students can work full time for a term on major projects.

-Grading system promotes exploration and risk taking.

- Promoted teamwork by eliminating student competition for GPAs and class rank.
- Heavy reliance on information technology.

IT not only for modeling and simulation, but for global communications with off-campus sites.

Global Perspective Program

- Project sites around world for 25 years.
- Many projects continue from team to team with same in-country sponsors.
- Major sites beginning to support graduate projects and faculty internships and consulting.
- Working to organize sites around research themes rather than geographic location.

5 Conclusions

- Half of economic productivity in US since 1950 due to innovation and underlying science and engineering.
 - Knowledge-based societies of next century will value even more highly research, innovation, and human capital as the principal assets of nations.
- Universities will have to be responsive to these conditions.

Conclusions (continued)

- Technological higher education must adapt to challenges of new millennium.
- Must prepare graduates to:
 - Work in interdisciplinary, multicultural teams.
 - Be adaptable with tolerance for ambiguity.
 - Promote culture that shares knowledge.
 - Remain current through lifelong learning.
 - Institutions need global partnerships to meet challenges.

Parallel Breakout Session II: Human Resources Development

Commentary

Hongying WANG *

Three very good papers were presented at this session:

- 1 CHEN Hao, Knowledge-based Economy and Human Resources Mobility
- 2 CHU Xuelin, University Role in Regional Development
- 3 Edward PARRISH, Preparing Scientists and Engineers for the 21st Century

The 1st paper was a detailed account of the emergence and evolution of China's post-doctoral system, particularly as it has developed in the Chinese Academy of Sciences. The post-doc system provides limited mobility within China's scientific community, a significant break from the past.

The 2nd paper was a thoughtful discussion of the multiple roles of the university in economic and social development, from generating to disseminating knowledge and from training personnel to energizing local culture. Particularly valuable was the paper's focus on regional development dynamics.

The 3rd paper started with a comprehensive discussion of the changing nature of the global economy and thus the necessity to change the education of engineers. It went on to present the model of Worcester Polytechnic Institute (WPI), which emphasizes flexibility, teamwork, and inter-cultural experience in addition to the technical training.

This group of papers addressed important issues regarding human resources development. Here are some questions that may call for further discussions:

1. Mobility: in addition to the post-doc system, are there other mechanisms to facilitate the mobility of human resources? What types of policy initiatives may be undertaken to further promote the free and efficient allocation of human resources?

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2. Role of university: the trend toward university-business cooperation certainly has positive consequences for the dissemination and application of scientific and technological innovation.

But should there be limits to university engagement in business activities, given its potentially negative impact on education and long-term basic research? Professor CHU mentions that his university has hundreds of companies. How does that affect the basic research and educational missions of the university?

3. Regional scientific development: universities apparently contribute a great deal to the development of their local regions. The Science and Technology University in Hefei, Anhui, is a good example. Most good universities in China are concentrated in a few cities. How does that influence the national pattern of innovation? What can be done to encourage the coordination and spread of their contribution to the national economy?

4. Training of university students: the WPI model addresses many new challenges for engineers in the new economy. Although it is not practical for Chinese universities to copy the model, it suggests ways to improve the training of engineers and university students in general. Rather than having students specialize as soon as they begin college, Chinese universities may benefit from introducing the concept of liberal arts education. Chinese colleagues say that some universities are beginning to think about such changes.

Plenary Session III: Changing Character of R & D

Chairman's Remarks

Charles LARSON*

According to recent estimates from NSF, industry investment in 1999 will be \$166 billion, up 12% over the estimated \$148 billion that was invested in R&D by industry during 1998. This \$166 billion represents 68% of the \$245 billion total R&D effort in the U. S. this year. The U. S. government will provide \$68 billion for R&D in 1999, or 28% of the total, while universities will provide \$6 billion of their own funds (2%) and non-profit organizations will provide \$5 billion (2%). In addition to its own funds of \$168 billion for R&D, industry will receive some \$20 billion from DOD, DOE, NASA, and other government agencies for R&D in 1999. Thus industry will perform some \$188 billion worth of R&D this year, or 77% of the total R&D effort in the U. S.

Industry's R&D investment, in current dollars, has increased 71% over the past five years and 126% over the past ten. These increases represent double-digit annual growth rates; in only three of the past ten years have the increases been less than 10%. Of the \$188 billion performed by industry on R&D in 1999, 71% will be for development activities, 22% will be for applied research, and some 7% will be for directed basic research. Directed basic research has increased from \$6.1 billion in 1994 to \$10.9 billion in 1999, an increase of 79%, or a rate of nearly 15% a year. Applied research has also grown significantly, rising from \$19.4 billion in 1994 to an estimated \$37.0 billion in 1999, or 91%.

The driver of these very strong investments in R&D is first and foremost increasing global competition. Other factors include the need to expand a firm's intellectual capital to compete in new businesses or new markets, and an interest in breakthroughs that can "change the rules of the game." Most companies are currently managing for growth of their businesses and of shareholder value. Other techniques being used by firms are to carefully control costs, to stimulate creativity and idea generation, to implement six-sigma quality-management practices in all business processes, to acquire additional intellectual capital or core competencies through mergers or alliances, to assess and

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protect their intellectual property, and to sell services in addition to products. Services will be a key to profitability in the future.

Two areas account for a large share of the increased R&D effort in industry—information technology and life sciences. Indeed, 8 of the top 10 R&D-investing companies in 1998 were from these sectors, as were 19 of the top 25 and 35 of the top 50.

Companies are also investing more in R&D abroad. A recent Commerce Department report, “Globalizing Industrial R&D,” indicated that R&D expenditures in the U. S. by foreign-owned companies tripled from \$ 6.5 billion in 1987 to \$ 19.7 billion in 1997. U. S. companies also increased their R&D spending in other countries, rising from \$ 5.2 billion in 1987 to \$ 14.1 billion in 1997.

It is expected that R&D investment by industry will continue to grow at a healthy pace as long as corporate profits and cash flows remain strong. In addition, globalization will remain a key challenge for most CEOs and CTOs. There is no question of whether or not to do it, but only how it can be done effectively and efficiently.

China's Basic Research at the Turn of the Century and Its National Goals

ZHANG Cunhao *

Following the common categorization of the West, China views the overall scenario of the S&T sector as comprising three components: basic research, applied research and technological development. In my opinion, basic research is the most fundamental and lively component of the three.

As a major source of knowledge innovation, basic research is, directly or indirectly, giving impetus to the economic boost and social progress and promoting the upsurge of human civilization.

For 4-5 centuries, basic science has proved to be a prime motive for technology innovation and economic boost in the west. Just as Newtonian mechanics formed the basis for the mechanical age and quantum mechanics the age of electronics and atomic and molecular engineering, so basic research conducted in the recent decades will certainly become the source of HiTech of the 21st century. For example, fundamental study in genomics, proteomics, cell biology and neuroscience, plus the active participation of mathematics, physics and chemistry, will definitely lead to enormous development of life sciences and biotechnology, resulting in radical changes in agriculture and medicine. The same trend will also happen in the field of novel materials and energy sources.

On the other hand, even in the West, the birth of the idea of setting national goals for basic research, or for scientific research in general, was relatively recent. It was not until during and after WWII that national goals were emphasized for research activities. At first, this was solely for defense purposes. However, it was soon realized by all major countries that setting national goals in basic research would extensively help enhance their economic competitiveness and, moreover, their comprehensive national strength.

Now I would like to defend why China particularly needs to emphasize "applied" basic research in its national goals for basic science and why China's science has more inclined to application. Some historians have attributed China's stagnation in the period 800 to 1900 AD to its adoption of utilitarianism, which in turn stemmed from Confucianism. Such critique could be true then, but not now. Back in the seventeenth century, when its population was just about 100 million, China still could have afforded to develop its own natural science, except that the ideological pattern of the

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then-dominating Confucianism did not allow this to happen. China, as of today, with close to 1.3 billion people, a per capita GNP still a 3-digit figure and arable land barely a tenth of a hectare per capita, cannot reject utilitarianism totally, but only to some proper extent.

Trying hard to take a large step towards modernization in the next few decades, it is not surprising that we should set our national goals for the S&T sector, including the pure research arena.

As of contemporary China, we try to set national goals for basic research in the following directions:

1 Part of basic research should be directed to become the precursor, source and backup force for new and high technology

We understand that competition in the HiTech fields is very acute indeed. Although I can cite a few instances, e. g. , Prof. Wang Xuan's work in the field of electronic publishing, where China does have ample room for development, I have to admit that, presently, China may have little chance in catching up with the leading edge technologies in, for instance, 0.1 μ m microelectronics. However, I would like to illustrate here that it would still not be too late for China to fight for a status in next round's competition in, e. g. , nanoelectronics. In the field of carbon nanotubes, Prof. Xie Sishen *et al.* , of the Institute of Physics, Chinese Academy of Sciences, have succeeded in preparing "very long" (2-3 mm) well-aligned nanotube arrays. Prof. Fan Shoushan's group, of Tsinghua University, on the other hand, made Gallium Nitride nanowires via a carbon nanotube-confined reaction. They also succeeded in planting nanotubes in regular patterns onto a microchip.

Following the first total synthesis by Chinese groups of scientists in the sixties, recent advances in life sciences have covered the sequencing of a number of genes for Chinese minorities as well as the cloning of disease-related genes, e. g. , one specifically related to deafness. The isolation of potent Chinese herbal medicine, e. g. , taxol (zishanchun, combats tumor), artemisinin (qinghaosu, cures malaria) and synthesis of their derivatives are also worth mentioning.

To trace back to the mid-20 th century, I would like to mention the recently deceased Prof. Wang Gan-Chang, who was among the first handful of physicists to advance in the early sixties the idea of inertial confinement fusion via the use of ultra-short laser pulses.

The design and manufacture of the yet unrivaled nonlinear optical crystals that operate in the UV/VUV region, especially BBO and LBO, has been another admirable achievement in the eighties through nineties. Both have already been widely used all over the world. They have very high damage threshold and were scheduled for use in two LLNL huge laser devices.

2 Basic research is being urged to provide an important basis for innovating and upgrading the conventional industries.

Under this category, I wish to cite the breeding of rice and other crops by Prof. Yu Zeng-Liang, of the Anhui Institute of Plasma Physics, CAS, through medium energy ion bombardment of their seeds. The result is an increase of 25% in yield of rice and much higher resistance to damage by water-logging. The technique has been successfully adopted in hundreds of thousand hectares.

Another example came with oil reservoir geophysics. CAS Member Liu Guang-Ding, with his colleagues, Dr. Yang Chang-Chun and others, of the Institute of Geophysics, CAS, advanced a theory for exploiting oil in thin-bedded layers, especially a 3-dimensional prestacking migration theory, which later developed into a set of software and became extremely successful in the exploitation of new oilfields. The accuracy of prediction for the reservoir depth could be as high as 2 thousandths and the yield per well up 100 times.

3 Basic research should pose radically new ideas for implementing the national strategies of “vitalizing the country via S&T and education” and “sustainable development”.

The projects on Global Change, Biodiversity, Water Conservancy, Environmentally-benign or Green Chemistry, the Science of Complexity and Biocomplexity, Financial Mathematics and Management etc. , all fall into this category.

About 6 years ago, we endorsed Prof. Peng Shi-Ge of Shandong University to divert his study of backward stochastic differential equations, a pure mathematics project, to applications in option pricing theory. The result is a nonlinear theory that encompasses the linear theory previous advanced by Black and Scholes. Peng's work also induced a surge in the study of financial math in China.

4 We fully understand that basic research leads not only to innovation, but also to “brand new” originality.

Although totally original ideas are very rare, they may often exert epoch-making influences, philosophically, or material-wise. Last March, CAS held in Beijing a commemoration ceremony for Albert Einstein's 120 th birthday. The Chinese science community pay our most esteemed tribute to this great scientist. His eventful findings are exemplary that basic research can serve as a mighty weapon for mankind in continuously probing into the material world and remaking it according to our motive.

5 Last but not the least, it is a bounden duty for basic research in China to foster and bring up senior scientists and engineers that are in severe shortage throughout China, as a rapidly developing country.

Following mature experiences of developed countries, a major fraction of future senior scientists and

engineers of China will emerge only as a result of basic research training.

For the last 12 years, within the scope of NSFC, about 15 per cent of general projects each year are allocated to scientists under the age of 35. Young grantees under this category totaled over 6,000. Furthermore, a Distinguished Young Scientists Program has been in action since 1994, with 120-180 grantees each year. These endeavors have been effective in alleviating the shortage of senior S&T personnel to some extent, although still a long way from fulfilling the present needs. It is gratifying that the government has recently approved more intensive measures.

From the above discussion, we all admit that basic research is pertinent to several national goals. To best implement these goals, care should be taken to allocate the national input of R&D resources adequately. The consensus is that, in the first place, R&D/GDP should be raised from the present 0.5% to a near-term $\sim 1.5\%$. Secondly, basic research spending should be raised from the present 6% to $\sim 10\%$ in the near future. Thirdly, it is advisable to allocate $\sim 1/3$ of the basic research spending through peer review processes. Fourthly, the ratio of 'pure basic' to 'applied basic' research should be adjusted from time to time to an appropriate proportion. In other words, we have to choose a trade-off between today and tomorrow. Thus, for over 10 years since the founding of NSFC, the input in pure and applied research was kept at about 30 : 70. Since the inauguration in 1998 of the '973' program, which is under MOST and is more mission-oriented, NSFC's emphasis undergoes some tuning. For example, the pure research input for the year 1998 was deliberately tuned up so as to realize a pure/applied ratio of 42.5 : 57.5.

China's present opportunity for modernization of the country and its science sector is rare and precious. During our endeavor for modernization, we have much to learn from the invaluable experience of our US colleagues. That is why we are so eagerly looking forward to this Beijing Symposium.

All my best wishes to our distinguished colleagues both at home and from abroad! I wish the symposium every success!

Thank you very much!

Globalization of R & D

John P. MCTAGUE*

Abstract By all measures, both research and development activities have spread across the globe at a rapid pace in the past few decades. A significant industrial cause is the increasing Gross Domestic Product (GDP) of many non-OECD member countries, and the shift to higher value added production with its higher R&D intensity. Another driving force is access to local academic and industrial talent and concentrations of activity, such as the California clusters of biotechnology, information technology, and automotive styling design, as well as the software cluster around Bangalore, India, which attract considerable cross-border investment and participation.

More fundamental research, whether academic, industrial, or government laboratory, has also rapidly increased its already collaborative and international character. Prominent examples are large-scale facilities such as the Large Hadron Collider, the International space Station, and the Pierre Auger cosmic ray project. Others involve complex data intensive efforts, which are globally coordinated to varying degrees, including the Human Genome Project and global climate change research.

An even broader trend is occurring in ordinary small-scale scientific research. The increasing ease of travel and the instant worldwide access to data provided by the Internet have enabled dramatic increases in interinstitutional collaboration both within and across national borders.

Today, fully half of all scientific papers worldwide involve multi-institutional authors. Moreover, during the last fifteen years the number of internationally co-authored papers has more than tripled. With one sixth of science reports being international, this may be the most global of human activities, and it may be a leading indicator for other fields.

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An Elementary Introduction to the Development of the High-tech Industries in China

XU Yongchang *

Abstract On the basis of the data considering the 4 high-tech industries of aerospace, computer and office machinery, electronics and communications, and pharmaceuticals in China, the paper makes an analysis of trends and characteristics of their development during the period from 1993 until 1997.

1. The general situation of the high-tech industries in China

1.1 The high-tech industries have begun to take shape and witnessed a rather rapid growth

The high-tech industries in China had a total of 9,814 enterprises in 1993, which increased to 10,043 in 1997. Their average annual number of employees totalled 3,216,000 in 1997, 42,000 less than that in 1993. Calculated at the constant price of 1990, their gross output value amounted to 641.76 billion yuan in 1997, increased by 55.5% over 1993, and in the meantime their added value increased from 63.64 to 127.42 billion yuan.

Table 1 The scale and trends of high-tech industries

	1993	1994	1995	1996	1997
No. of enterprises	9814	9168	10882	10766	10043
No. of employees (ten thousand)	325.8	326.2	327.9	377.5	321.6
Gross output value (100 million yuan)	2511.6	3043.4	9301.4	4889.0	6417.6

In 1997, the number of enterprises in high-tech industries made up 2.4% of that of the entire manufacturing industry, the number of their employees, 4.9% and their gross output value, 12.2%. It may be said that high-tech industries have begun to take shape although their share in the entire manufacturing industry is yet relatively small.

Judged by the trends in the past five years, high-tech industries grew comparatively rapidly. The

* The task, commissioned by the Planning Department, Ministry of Science and Technology, is undertaken by the National Research Center for science and Technology for Development. Xu is a fellow in the Center.

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growth rate of their gross output value and added value, as well as the numbers of their enterprises and employees, were all higher than those of the entire manufacturing industry. From 1993 to 1997, the average annual growth rate of their gross output value and added value was 26.4% and 19.0% respectively, high than that of the entire industry by 9.4 and by 0.1 percentage points.

Table 2 The upward trends of the gross output value and added value of high-tech industries (1993—1997)

	1993	1994	1995	1996	1997
Gross output value (10 million yuan)	2511.6	3043.4	4301.4	4889.0	6417.6
Increase over the preceding year(%)	—	21.2	41.3	13.7	31.3
Added value (10 million yuan)	636.4	696.8	890.0	976.9	1274.2
Increase over the preceding year(%)	—	9.5	27.7	9.8	30.4

Against the macro background of the rapid and sustained economic growth in China, the vitality of high-tech industries has been further enhanced and high-speed growth has become an outstanding feature of the development of our high-tech industries in recent years.

1.2 The position of high-tech industries is steadily raised and their role enhanced

Compared with 1993, the number of enterprises in high-tech industries increased only by 229 in 1997, whereas the number of employees even decreased. Both numbers accounted for a comparatively small proportion in the entire manufacturing industry, only 2.4% and 4.9% respectively. However, the gross output value and added value of high-tech industries made up greater proportions: 12.2% and 8.1% respectively.

The proportion accounted for by high-tech industries of the total pretax profit of the entire industry was 6.0% in 1993 and increased to 10.0% in 1997.

Table 3 Proportions of chief indexes accounted for by high-tech industries of the entire industry's respective totals(1993—1997)

	1993	1994	1995	1996	1997
No. of the enterprises	2.6	2.2	2.5	2.4	2.4
No. of the employees	5.1	4.5	4.8	5.5	4.9
Gross output value	8.9	8.0	10.7	10.4	12.2
Added value	6.6	5.7	6.2	6.7	8.1
Sales income	7.3	6.6	7.5	7.3	8.8
Pretax profit	6.0	5.7	6.5	8.6	10.0

Judging from the export of high-tech industries, we can see that they have occupied a certain position in the entire manufacturing sector. In 1995, the value of exports delivered by high-tech industries amounted to 111.69 billion yuan, making up 15.5% of the entire manufacturing industry's total and 33.5% of the sales income (export intensity), the latter being higher by 17.3 percentage

points than that of the entire manufacturing industry.

The data shown above reflect that in the entire manufacturing industry, high-tech industries made a larger contribution in spite of a smaller scale. As viewed from the trends, in comparison with the entire manufacturing industry, the growth rate of such indexes as gross output value, added value, sales income and pre-tax profit in high-tech industries was much faster. It can be thus seen that their position in the entire manufacturing industry has been gradually raised and their role steadily enhanced.

1.3 The characteristics of high-tech industries are not distinctive yet

Generally speaking, high-tech industries should be characteristic of high-tech intensiveness, high effectiveness and high added value, which features are not pronounced with the high-tech industries in China yet.

The magnitude of R&D expenditure is one of the major indicators for measuring the intensity of technology and knowledge of an industry. Calculated on the basis of the data of large and medium-sized industrial enterprises in 1996, the proportion of R&D expenditure of the entire manufacturing industry in added value was 2.3% and that of the high-tech industries was 4.8%, only twice as high as the former. Among the four high-tech industries, only the aerospace industry had an edge on the others, with its R&D expenditure reaching 13.3%, whereas the percentage was only 0.7% for the electronics and communications industry, far below the average level of the entire manufacturing industry. Obviously, the high-tech intensity of the high-tech industries as a whole, a distinguishing feature peculiar to them, was not prominent then.

Labour productivity is an important indicator of productivity level and economic benefit. The high-tech industries should of course have higher productivity. In 1997, their labour productivity was 39,600 yuan/person, 1.65 times of that of the entire manufacturing industry, 24,000 yuan/person. From the comparison we can see, there was not much advantage, with the high-tech industries, wherein the aerospace industry attained a level of only 18,500 yuan/person, even lower than the average one of the entire manufacturing industry.

As regards the proportion of added value in the gross industrial output value, it was only 19.9% with the high-tech industries in 1997, less than that of the entire manufacturing industry by 10 percentage points. In particular, the proportion with the computer and office machinery industry which saw a comparatively quick growth was merely 17.6% and that with the electronics and communications industry, the lead in high-tech industries, was no more than 18.1%. Such cases reflected a tendency shown by the high-tech industries in China towards quicker growth in the size of output value but a corresponding lag in the increase of output. This illustrates from one aspect that our high-tech industries do not possess the distinguishing feature of high added value production for the time being.

1.4 The contribution of high-tech industries to the national economy is limited yet; unable to gain an upper hand in international competition

In recent years, the high-tech industries in China, especially the computer / office machinery and electronics / communications industries, have seen a quite rapid growth; but taken as a whole, the high-tech industry is still in its initial stage of development, occupying a minor share in the national economy. From 1993 to 1997, the proportion of high-tech industries' added value in that of the entire manufacturing industry basically remained at 1.5% to 1.7%. In 1997, the proportion increased by a comparatively large margin, no more than 8.1% however. Our high-tech industries have not established their dominant position yet, therefore both their contribution to the national economy and impetus given to economy and society are limited.

According to the statistical data published by US national science Foundation, in the export value of the high-tech industries in 68 countries in 1995, the United States occupies the highest share (19.2%), followed by Japan (11.9%), United Kingdom (7.2%) and Germany (6.9%); the shares of South Korea, Singapore and China were 4.1%, 7.7% and 1.8% respectively.

In so far as individual high-tech industry is concerned, the export of our country's pharmaceutical industry made up 2.1% of the total of all countries in the world, exceeding that of Japan (1.9%), Canada (0.9%) and Singapore (0.7%). The export of our electronics and communications industry made up 2.3% of the world's total, slightly higher than that of Italy. The export of computer / office equipment and aerospace industries made up 1.4% and 0.3% of the world's total respectively.

It can be seen from the index of export, which reflects the competitive power of our high-tech industries, that our high-tech industries, whether as a whole or as individual ones, occupy a very small share in the world market owing to weak competitive capacity. Compared with either developed countries or newly emerging industrialized ones, our country has a long way to go in this regard.

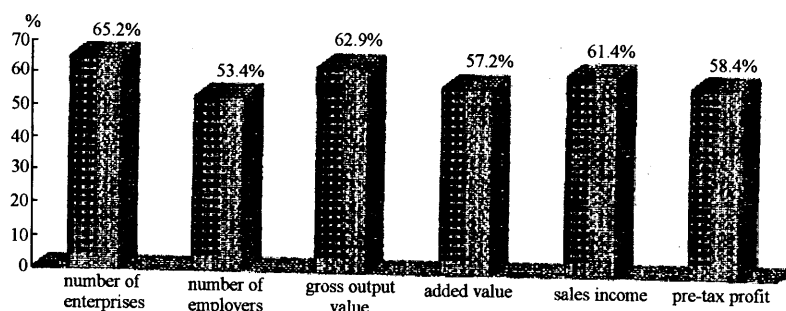


Fig. 1 Proportion accounted for by the chief indexes of the electronics and communications industry of the respective total of the entire high-tech industry

2. The characteristics of various high-tech industries in their development

2.1 The electronics and communications industry is the lead

In 1993, the electronics and communications industry had altogether 5,692 enterprises, 1685,000 employees and a gross output value of 139.99 billion yuan, accounting for 58.0%, 51.7% and 55.7% respectively of the correspondent totals of high-tech industrial enterprises; its added value was 31.63 billion yuan, sales income, 122.63 billion yuan and pre-tax profit, 9.69 billion yuan, accounting for the correspondent totals of high-tech industrial enterprises 49.7%, 56.4% and 52.8% respectively. Obviously, it became the mainstay of high-tech industries with its leading position in chief indexes.

It can be seen from the trends of chief indexes that the industry grew at a quick pace. In 1997, the number of its enterprises was 6552 and that of its employees was 7,287,000, up by 15.1% and 30.4% over 1993 respectively. Its sales income and pre-tax profit were 293.37 and 24.97 billion yuan, up by 39.2% and 157.7% over 1993, respectively.

The rapid growth of the industry has led to a steady improvement of its advantageous position in high-tech industries.

2.2 The computer and office machinery industry grows most rapidly

In recent years, the growth of the industry has been particularly noticeable with a rate far exceeding the other three industries. As shown by the trends of its four chief indexes—gross output value, added value, sales income and pre-tax profit, all of them witnessed an increase by more than 4 times over 1993 in 1997, wherein pre-tax profit witnessed an increase even by 8 times; those of the electronics and communications industry were meanwhile up by two times only. From the data shown in Table 3 one may see that the growth rate of the industry was not only considerably higher than the entire manufacturing industry, but also far exceeding the average rate of the entire high-tech industry.

Table 4 Growth rate of the computer and office machinery industry (1993—1997) %

	Average annual growth rate of the computer and office machinery industry	Average annual growth rate of the entire manufacturing industry	Average annual growth rate of the entire high-tech industry
No. of enterprises	9.3	2.7	0.6
No. of employees	7.5	0.7	-0.3
Gross output value	61.1	17.0	26.4
Added value	44.7	12.9	19.0
Sales income	58.5	16.1	21.8
Pre-tax profit	74.0	9.0	23.5

With the vigorous development of the industry, the proportion its various indexes accounting for the respective totals of the entire high-tech industry has steadily increased. Compared with 1993, the proportion of four chief indexes increased by 9.9, 7.7, 11.1 and 11.7 percentage points respectively in 1997.

The number of employees in the industry accounted for the smallest proportion (5.3%) of the total of all high-tech (16.0%), added value (14.2%), Sales income (17.0%) and pre-tax profit (15.7%) were comparatively larger. As a newly emerging industry, it has made an increasingly greater contribution to the entire high-tech industry with a strong momentum of development. Judged by the trends of development, with a steady rise in position and effect the industry might replace the pharmaceutical industry and take the 2nd place among high-tech industries.

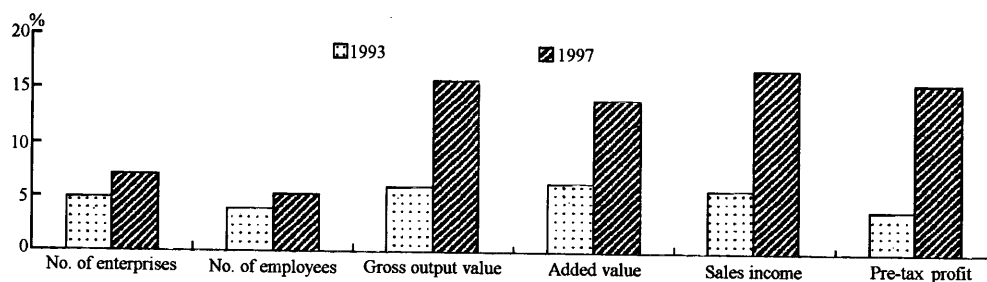


Fig. 2 Percentage change of the chief indexes of computer and office machinery industry in those of the entire high-tech industry (1993, 1997)

2.3 The adjustment range of pharmaceutical industry is comparatively wide

In the process of transforming into a socialist market economic system, the industry has undergone a large-scale adjustment, becoming the only one in the four high-tech industries that cut the number of both enterprises and of employees by a big margin. Compared with 1993, its enterprises and employees in 1997 were reduced by 848 (24.6%) and 154,000 (16.3%) respectively.

In spite of such a large-scale reduction, other indexes of the industry increased in varying degrees. From 1993 to 1997, the average annual increase in its gross output value was 7.1%; added value, 6.3%; sales income, 3.5%; and pre-tax profit, 7.4%. Its labour productivity rose from 22,000 to 34,000 yuan/person, indicating that the industry scored the initial success from personnel reduction by enhancing efficiency.

The proportion made up by various industries' indexes of the entire high-tech industry's respective totals has resulted in an aspect of reciprocal up and down between them. Compared with the rapidly growing electronics/communications and computer/ office machinery industries, the pharmaceutical industry has in recent years remained in the stage of adjustment. Therefore, the percentages made up by the former two industries' various indexes have all gone up while those of the latter industry have all come down.

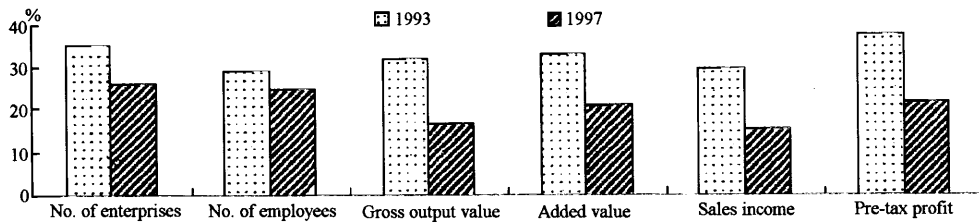


Fig. 3 Percentage change of the chief indexes of pharmaceutical industry in those of the entire high-tech industry(1993,1997)

In spite of the considerable decrease in the percentages of its chief indexes, the scale and production level of the industry have remained in second place, next to the electronics and communications industry, among high-tech industries. In 1997, its added value amounted to 26.65 billion yuan, making up 20.9% of the entire industry's total, equating to the sum of those of the computer /office machinery and aerospace industries. The industry brought in 9.15 billion yuan of pre-tax profit, more than the sum of those brought in by the above-mentioned two industries.

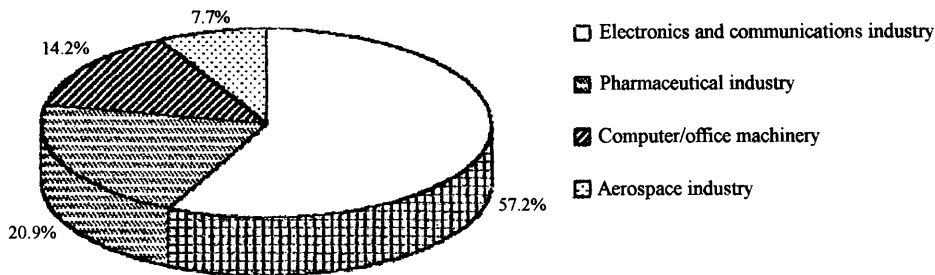


Fig. 4 Proportion of added value accounted for by various high-tech industries of the entire high-tech industry's total(1997)

2.4 Aerospace industry is large in scale but not in an advantageous position

In 1997, among the 10,000 enterprises of the entire high-tech industry, 185 belonged to the aerospace industry, making up only 1.8%. However, the number of employees of the industry was 53,800, increasing by 38,000 over 1993, making up 16.7% of the entire high-tech industry's total. The industry occupies a dominant position in scale, especially in the number of employees which averaged some 3,000 per enterprise, far more than that of the other high-tech industries-averaging 200~300 per enterprise. The gross output value of the industry averaged 170 million yuan per enterprise, larger than that of the other three industries by some 4 times. Likewise, the sales income and pre-tax profit of the industry are more than those of other industries. It is clear that a distinguishing feature of this industry is the small number and large size of its enterprises which are mostly large and small ones.

Another distinguishing feature of the industry is the high intensity of its R&D expenditure. In

1996, the R&D expenditure of the entire manufacturing industry in China totalled 14.33 billion yuan, accounting for 2.3% of its added value. The R&D expenditure of four high-tech industries amounted to 2.79 billion yuan, accounting for 4.8% of their total added value. Among the four industries, the aerospace industry accounted for 13.3%, the highest percentage, the rest three industries accounted for 3.8%, 3.6% and 0.7% respectively.

As to the proportion accounted for by added value of gross output value, it was 31.2% in 1997 for the industry, the only high-tech one whose added value was above the average level of the entire manufacturing level. This shows that the industry has achieved a comparatively higher added value in its production.

By comparison, the labour productivity of the industry is lower. In 1997, the labour productivity of high-tech industries averaged 40,000 yuan/person. The labour productivity of the computer and office machinery industry was the highest, reaching 106,000 yuan /person, followed by that of the pharmaceutical and electronics/ communications industries, 34,000 and 13,000yuan / person respectively, all above the average level (24,000 yuan/person) of the entire manufacturing industry, whereas that of the aerospace industry was only 18,000 yuan/ person. Judge by the state of affairs in the past five years, the industry has all along lagged behind in labour productivity.

Generally speaking, the growth rate of the industry in recent years has been comparatively slow and its share in high-tech industries steadily declined. Except for the number of employees, it ranked below the other three industries in the rest of the indexes. In short, the aerospace industry has hitherto not exploited its advantages in scale and R&D intensity, which is reflected by its low productiveness and achievements.

As stated above, the development of four high-tech industries had different characteristics from 1993 to 1997. The electronics and communications industry occupied a weighty position in the entire high-tech industry by making up more than 50% of the latter's various indexes. The computer and office machinery industry exhibited its vigor in forging ahead. The pharmaceutical industry achieved initial success while in the stage of adjustment by reducing personnel to enhance efficiency. The aerospace industry, with large and medium-sized enterprises as its mainbody, has yet to realize the advantages of large scale and high R&D intensity in order to improve its productiveness and achievements.

Plenary Session III: Changing Character of R&D

Commentary

Richard P. SUTTMEIER *

This session contained presentations from NSFC President ZHANG Cunhao on Chinese perspectives on basic research and from John MCTAGUE on the globalization of R&D. President ZHANG's remarks indicated that in important ways, Chinese thinking about basic research were both consistent with and different from Western thinking. The differences stem in part from China's level of economic and technological development and from the characteristics of its national research priorities and system of research institutions.

ZHANG noted that basic research goals are intended to address five main scientific and technological development objectives. As he presented these, he illustrated them with examples of Chinese research achievements in each. The five include:

- preparing for future high technology development in ways which would allow China to leapfrog into leadership in the development of future technological trajectories and in exploiting future industrial opportunities (e. g. , work in nanoelectronics)
- aiding in the upgrading, or renovation, of traditional industries (e. g. , work in seed breeding, geophysical work in oil prospecting)
- providing radically new ideas for reconceptualizing practical problems (e. g. , mathematical applications in finance)
- generating truly original ideas which may not have immediate practical application
- serving higher education and the advanced training of high level manpower

President ZHANG noted that expenditures on basic research had gone up steadily since NSFC was founded, and argued that basic research support should gradually come to occupy a larger share - 10%, up from its present 6% - of the nation's R&D spending. He also noted how, with the initiation of the National Basic Research Program ("973" - a program of targeted, mission-oriented, top down, "basic" research), the share of NSFC funding for "pure," investigator initiated research has been increased - adjusted upward - from 30% to 42.5% of NSFC research support. In this sense,

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NSFC is playing a role analogous to the “balance wheel” function that Dr. ATKINSON attributed to US NSF.

Finally, President ZHANG noted that about 1/3 of Chinese basic research was peer reviewed. This observation prompted some discussion about peer review, with Dr. ATKINSON noting that this figure seemed remarkably low by US standards. He suggested that peer review actually played a pervasive role in US government support for R&D, even in programs of applied research where investigator initiatives were secondary to the setting of agency goals. Professor HART commented that the NSF model should not be regarded as the only model of support for basic science and exploratory technological research in the US, and pointed to such administratively directed programs as those sponsored by DARPA. Dr ATKINSON agreed, but also reiterated his belief that these too are guided by peer review. Dr. MU commented that he thought peer review in China might operate somewhat differently than in the US. In the initial review of Chinese project applications, there is anonymous, “black-boxed” peer review. This then is followed by selection committee assessments that allow for additional criteria, beyond peer judgements, to be applied.

The presentation by Dr. MCTAGUE explored the reasons for the globalization of R&D and presented a number of measures of how extensive the process has become. Using data from the latest USNSF indicators report, MCTAGUE illustrated the trends in globalization as seen in corporate R&D patterns, big science projects (of both the concentrated and distributed varieties), and in “ordinary, small-scale” research. The reasons for globalizing trends differ somewhat among the three areas, but common features include:

- the diffusion of scientific capabilities around the world
- higher standards of living and new market opportunities in parts of the world beyond the OECD countries
- the worldwide search for talent by industrial firms and the worldwide search for collaborators by research scientists, and
- the ease of travel as a result of relatively low cost transportation and the advent of virtually costless and instant communications and access to data via the Internet.

With its rich human and institutional resources for R&D, the US is especially well suited to benefit from the globalization of R&D, according to MCTAGUE. Data on foreign corporate investment in US R&D, foreign students studying in US universities, and patterns of the coauthorship of scientific papers were used to support this observation. While it was pointed out by Ms. BOND that the centrality of the US in coauthorship may be declining somewhat, and that there has been a downturn in Asian students coming to the US for graduate study, there are still lessons to be had from the US case; sustained national support for excellence in R&D can make a nation’s scientific enterprise a magnet for talent and investment from around the world in an age of globalization.

Dr. MCTAGUE suggested that the globalization trends identified should continue into the foresee-

able future, making physical distance an increasingly less important factor in scientific cooperation and making scientific research, perhaps, "the most global of human activities." At the same time, the increasingly high costs of industrial R&D are forcing both increasing cooperation among competitors and increasing international industrial concentration, as firms merge and consolidate (as in the automobile industry) in the search for scale economies. Thus, patterns of international S&T will show both new forms of centralization - as seen in industrial consolidation and in some big science activities - and new types of decentralization in a spatially dispersed, distributed community linked via electronic communication.

In the discussion which followed, attention was given to the implications of the globalization of R&D for China-US cooperation in science and technology. It was suggested that globalization will condition bilateral ties - US perceptions of cooperation with China will increasingly be seen through the lenses of globalization and, as Professor CHENG Siwei had pointed out in his dinner remarks the previous evening, managing the effects of globalization is one the more challenging tasks facing China's science and technology development strategies, including relations with the US. Professor CHENG had noted, in particular, how China seeks to attract foreign corporate investment in research without having its research system become simply an appendage of the innovation systems of multinational firms.

It was pointed out that this concern for the possible costs of globalization was evident in the US as well, with some observers questioning whether such trends as the growth of foreign investment in US R&D, and the large number of overseas students coming to US universities, didn't pose a danger of US intellectual assets being drained from the country. Similarly, questions were asked about the high proportion of foreign born students in science and, especially, in engineering graduate programs, and about the growing reliance on foreign born scientists and engineers in US industry. Dr. MCTAGUE repeated his belief that by its very nature, there is mutual gain to be realized from the globalization of R&D.

Professor SUTTMEIER noted that in spite of the mutual gains, the political processes which shape the environment for international cooperation often focus on "relative gains" - whether one side gets disproportionate benefits relative to the other. It was suggested that the time is right for us to begin to anticipate possible future conflict over relative gains in US-China S&T relations in order that they not escalate into higher level conflict, as happened with S&T relations with Japan. SUTTMEIER noted that in the relative gains conflicts with Japan, much attention was focused on the issue of "asymmetrical access," where Japanese investigators had access to areas of US R&D while US investigators could not access comparable areas of Japanese R&D. These problems were, in part, a reflection of the different institutional arrangements and programmatic emphases in the two countries. SUTTMEIER asked whether we could expect similar kinds of problems developing in US relations with China, or whether conditions in the early 21st century, as a result of the positive trends noted by MCTAGUE-e. g. , the drastically reduced costs of collaboration, the international flows of human resources in science and education, etc. — will make the problems of institutional and pro-

grammatical asymmetry less of an issue. The differences in approaches to basic research, as indicated in President ZHANG's remarks, point to asymmetries in institutions and program assumptions, and may suggest the need for anticipatory discussions on how conflicts from asymmetries can be avoided, and assumptions harmonized.

Appendices

1. Agenda

Beijing, P. R. China, October 24-27, 1999

24 Oct. (Sun.)

24 Oct. (Sun.)	Morning	Optional sightseeing for US participants
	5:00 pm	Opening Session (JUFUYUAN at Friendship Palace, Friendship Hotel) Welcoming remarks addressed by Prof. ZHOU Bingkun, Dr. BLANPIED, Prof. XU Weixuan and Dr. RATCHFORD;
	Evening	Reception (JUFUYUAN at Friendship Palace, Friendship Hotel)

25 Oct. (Mon.) Meeting room #202, Science & Technology Hall, Friendship Hotel

TIME	PARTICIPANT	TOPICS
9:00-10:30	Plenary Session I. Information Requirements for Science Policy Chair: XU Weixuan	
	US	The Context for International R&D Cooperation David M. HART, Harvard University
	PRC	Technological Innovation; Analysis Implication for Chinese S&T Policy FENG Xuan, Ministry of Science and Technology
	Commentators	William BLANPIED, NSF LI Shantong, Development Research Center of State Council, P. R. China
10:30-10:45	Coffee Break	
10:45-12:30	Plenary Session II. Human Resources for Science and Engineering Chair: Thomas Weimer	
	PRC	The Knowledge-based Economy & its Challenge to China's High Education XUE Lan, Tsinghua University
	US	Opportunities for Chinese and American Universities in the Knowledge-based Economy Richard C. ATKINSON, University of California
	PRC	Strategic Management on Technology Innovation CAO Zhijiang, Legend Holdings Limited
	Commentators	Gerald KEUTSCH, NIH XU Weixuan, Institute of Policy and Management, CAS
12:30-13:50	Lunch	

2:00—5:00pm	Parallel Breakout Session, Part I Information Requirements for Policy-making and R & D Chair: CHANG Qing	
	US	Using National Accounts to Assess the Role of R&D in the U. S. Economy Sumiye OKUBO, Bureau of Economic Affairs, US Department of Commerce
	PRC	Methodology for Evaluating International Competitiveness of High-tech Industries MU Rongping, Institute of Policy & Management, CAS
	US	Indicators of International Science & Technology Cooperation and Interaction Jennifer Sue BOND, National Science Foundation
	Commentators	NIE Min, Huazhong University of Technology David HART, Harvard University
2:00—5:00pm	Parallel Breakout Session, Part II: Human Resources Development Chair: Thomas Ratchford	
	PRC	Knowledge-based Economy and Human Resources Mobility—The Practice of Postdoctoral System in China CHEN Hao, Bureau of Science & Technology Policy, CAS
	PRC	University Role in Regional Development CHU Xuelin, Univ. of Science and Technology of China
	US	Preparing Scientists & Engineers for the 21st Century Edward PARRISH, Worcester Polytechnic Institute
	Commentators	XUE Lan, Tsinghua University
5:00—6:00pm	Commentators and Reporteurs Meeting	
6:30pm	Dinner hosted by the NSFC (Friendship Palace, Friendship Hotel)	

26 Oct. (Tues.), Meeting room #202, Science & Technology Hall, Friendship Hotel

TIME	PARTICIPANT	TOPICS
9:00-10:30	Plenary Session III. Changing Character of R & D Chair: XUE Lan	
	PRC	China's Basic Research at the Turn of the Century and its National Goals ZHANG Cunhao, National Natural Science Foundation of China (NSFC)
	US	Globalization of R&D John MCTAGUE, Ford Motor Co. (retired)
	Commentators	FANG Xin, Institute of Policy and Management, CAS Richard SUTTMEIER, University of Oregon
10:30-10:45	Coffee Break	
10:45-12:25	Plenary Session III (cont). Changing Character of R & D Chair: Charles LARSON	
	PRC	Changing Role of Industrial R&D FANG Aihua, Wuhan University
	US	The Evolving Face of Science and Technology Policies Gerald J. HAHE, Office of Science and Technology Policy (OSTP)
	Commentators	WANG Shouyang, NSFC Richard ATKINSON, University of California
12:25-13:50	Lunch	
2:00-3:30	Plenary Session IV: Summary Reports from Breakout Sessions I & II Chair: XU Weixuan	
	General discussion and summary of the first day & morning	
3:30-3:45pm	Coffee Break	
3:45-5:00	Final Plenary Session V: Agenda for the Future Chair: J. Thomas RATCHFORD, GMU Overall Discussion, Agenda for the Future	
5:00-6:00	Commentators and Rapporteurs Meeting	

27 Oct. (Wed.) Meeting room on the 3rd floor of Building 5

9:30-11:30	1. Coordinating Groups Meeting 2. US participants: Scientific visit
Afternoon	Sightseeing
Evening	Leaving Beijing for Shanghai by group

General Rapporteur

William BLANPIED, National Science Foundation

Rapporteurs

Hongying WANG, Maxwell School, Syracuse Univ.

MU Rongping, Inst. Science Policy & Management Sciences, CAS

XUE Lan, Tsinghua University

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