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THE NEW INDUSTRIAL REVOLUTION:
ACHIEVEMENT AND UNCERTAINTY IN THE SEARCH FOR RESEARCH AND INNOVATION STRATEGIES

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Introduction.

As the new millennium approaches, the importance of science and technology for China's security, economic, and environmental problems has again captured the attention of China's leaders. As a result, strategies for enhancing research and innovation capabilities have come to occupy a more important position in Chinese development thinking. But devising effective policies has also become more challenging. In spite of successes, policy makers face moving targets, as technological frontiers, the structures of the Chinese industrial and research systems, and the terms of China's engagement with the international environment, all continue to change. In addition, Chinese leaders are also forced to recognize that the alleviation of complex problems affecting the creation of a culture of innovation in China awaits the gradual evolution of professional, economic, and legal norms, and is not subject to easy policy remediation.

Heightened elite attention to science and technology (S&T) in late 20th century China is prompted in the first instance by Chinese perceptions that the interrelated factors of globalization and rapid technological change are fueling a new industrial revolution in the world's economy. Globalization, made possible by the reduction of political barriers to international trade and investment and by changes in transportation and telecommunications technologies, is binding the world's economies together in new ways, and is creating opportunities for extraordinary well being for those who can master its dynamics.[1] Rapid technological change is producing new technical means for wealth creation, engendering a "knowledge economy" of science-based, high value added production and modern information technologies capable of achieving remarkable economic efficiencies. In addition, the "dematerialization" of production and the substitution of information for energy which characterize industrial activity in the knowledge economy, provide revolutionary technological possibilities for managing environmental problems.

These possibilities for economy and environment are all matters of great interest to Chinese elites. As one official of the Chinese Academy of Sciences put it to us in explaining recent S&T initiatives, "The train (the new industrial revolution) is leaving the station. We want to be sure we are on it." China paid dearly for missing the last industrial revolution; we can readily appreciate the new sense of urgency that it not miss the next. This worry, currently, may be most acute where the possibilities presented by the new industrial revolution intersect China's perceived national security needs.

The Gulf War, and now the NATO war against Yugoslavia, have demonstrated that the knowledge economy can also sustain a "revolution in military affairs," in which new materials get combined with a full array of information technologies to transform the nature of weaponry and of war.[2] In the wake of the Kosovo action, the bombing of the Chinese embassy in Belgrade, the release of the report of the House Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China (the "Cox Committee"), and with plans for the development of a theater missile defense system in East Asia unfolding, high technology issues and national security concerns have combined to make research and innovation strategies more pressing than ever for China's leaders. Thus, as the 20th century draws to a close, China's sense that technologically superior hegemonic forces are frustrating the pursuit of its interests is a painful reminder that China is, indeed, not yet "on the train."

Globalization, apparently, is a condition for the new industrial revolution; one can't participate in the latter, it seems, without participation in former. But, to capture value from globalization, and to "win" from participation in it, requires that a nation have assets which are valued in the globalization process. These include effective programs and institutions for research and innovation and an internationally capable cadre of scientists and engineers. Chinese leaders understand that participating in the international economy by relying, chiefly, on a large pool of low cost labor, is not a winning strategy in the globalization game. Instead, the challenge is to create national capabilities for research and innovation which will make the globalization process work in China's favor.

This paper examines the programmatic initiatives and reforms in science and technology from the early 1980s to the late 1990s intended to achieve this objective. We find that these have produced some of the most supportive conditions for scientific and technological development that China has seen over the past 100 years. At the same time, we also note that serious problems with the research and innovation systems remain, and that these could compromise the vision of an innovative and technically progressive China in the early years of the 21st century which is cherished by today's technocratic leadership. These include persistent systemic problems, new issues raised by the very success of earlier reform efforts, rapid technological change in the global economy, and, more recently, uncertainties in the international political environment. Thus, while much progress has been made in enhancing national scientific and technological capabilities, the goal of catching up with the world's technological leaders remains an enduring source of anxiety, frustration, and challenge for China's leaders.

The Origins of Concern.

China has had forewarnings that "the train was preparing to leave the station" for some time. It needed to acquire an appreciation of how a modern "train" - the science based economy - operates, however, and to see "the wheels" begin to turn, before the sense of urgency set it. The acquisition of that appreciation is discernible in the evolution of Chinese policy thinking over the past 20 years, as Soviet inspired, Maoist era assumptions about innovation and intellectual property, the social and economic status of technical intellectuals, the organization and funding of research, the role of peer review, etc. - gave way to thinking and practices more characteristic of the advanced capitalist economies.[(3)]

A sensitivity to the challenges for China in a world of rapid technological change was evident in the founding events and principles of Deng Xiaoping's reform era, such as the 3rd Plenum of 11th Party Congress and the 1978 National Science Conference of the same year, events which were infused with the themes of S&T development.[(4)] As the reform and open door policies unfolded in the 1980s, and active technology enhancement programs were introduced (see below), appreciation for modern technology became more acute. The idea of replacing "extensive" with "intensive" growth began to take hold, concerns for improvements in energy savings and product quality through new technologies began to grow, Chinese understandings of high value added production became more astute, and the relationships between high technology and modern warfare came into sharper focus. Along the way, Chinese elites became enthusiastic readers of Western prophets of technology-driven societal transformations, such as Alvin Toffler. Thus, by the end of the 1980s, China had begun to take the challenges of high technology development quite seriously.[(5)]

The Gulf War, the accelerated growth of the global high technology economy in the early 1990s, and careful assessments of the roles of science and technology in sustaining (or failing to sustain) the development experiences of China's East Asian neighbors brought even more focus to the Deng-era aspirations for science and technology. When that era finally ended, a new group of leaders were in place who, by virtue of education and career experiences, had a much more informed understanding than their predecessors of global technological trends, and where China stood in relation to them. [(6)] This understanding found expression at the National Science Conference of 1995 and its culminating document, the "Decision to Accelerate the Development of Science and Technology."[(7)] Just as the 1978 National Science Conference signaled the dawn of the Deng era, so the 1995 meeting, with its call for "revitalizing the country through science and education" (kejiao xinguo), marked the introduction of new S&T policy initiatives from the emerging post-Deng leadership.[(8)] Before discussing these post-Deng policy themes, let us review briefly the objectives and accomplishments of S&T policy during the Deng-era.

The Deng-era Record of Enhancing Technological Capabilities.

From the late 1970s to the mid-1990s (roughly, the period covered by the 6th to the 8th Five Year Plans), China launched a series of ambitious initiatives for enhancing the nation's technological capabilities. These efforts involved "walking on two legs" - exploiting S&T resources internationally and promoting a variety of domestic policy changes, including significant reforms of institutions for science and technology and a series of programs for focusing R&D efforts on national objectives.[(9)]

Exploiting the International Environment. Beginning in the late 1970s, China initiated an extensive - and expensive - set of programs to acquire foreign technology. Between 1979 and 1993, for instance, it spent about $US 70 billion on technology imports as part of an overall technology renovation (jishu gaizao) effort.[(10)] The extent to which foreign technologies have been adopted over this period is evident across a variety of industries, from automobiles to textiles. In the huge machine building industry, for instance, one survey reported that by the early 1990s, "...about two thirds of the technology employed in production in the machinery industry is directly acquired from overseas suppliers."(11)

These programs of technology transfer from abroad were much less coordinated than they appeared, and were characterized by many poor choices of technology, considerable duplication, and serious inattention to the problems of assimilation. Nevertheless, they did succeed in moving the process of industrial transformation forward, leading to gains in productivity, notable savings in energy use, significant improvements in product quality, and in facilitating the rapid growth of China's export economy during this period. In addition, the actual technology transfer process had positive spillover effects as modern management attitudes and practices diffused into the Chinese system.(12)

In addition to the technology acquisition efforts noted above, China has sought to exploit other opportunities in the international environment. These include, of course, the extensive effort to send students abroad for advanced training, success in attracting foreign investment (and much technology via foreign invested projects), and strategies to take advantage of the facilitative resources available from international organizations - especially the World Bank and the UN agencies. World Bank loans, for instance, have allowed China to upgrade the quality of laboratories in universities (thus facilitating the establishment of modern graduate education), have been important for the implementation of the "Key Laboratories" program (discussed further below) which is intended to raise the quality of research and advanced training of 155 laboratories in universities and research institutes, and in the establishment of a string of national engineering research centers.

Reforms in the S&T System. By the early 1980s, Chinese scientists and science administrators also began to realize that the system of science and technology institutions, inspired by the Soviet Union in the 1950s, was in need of reform. One important change was the promotion of university based research (which had been seriously neglected in the pre-reform period), and the initiation of graduate programs, efforts which have had a notable effect on the composition of Chinese research performance. By the mid-1990s, for instance, university-based researchers had become the recipients of the majority of grants from the National Natural Science Foundation of China (discussed further below) and are responsible for the majority of published papers in science and engineering.(13)

The main thrust of reform thinking, though, was to encourage a closer relationship between research and production by breaking the vertical coordinating functions of the old planning system and encouraging horizontal, market-mediated ties between research institutes (and universities) and enterprises. In 1985, these objectives were formalized in the "Decision on Reform of the S&T Management System." The reform Decision was based on the assumptions that more effective research-production linkages could be achieved by (1) making enterprises more economically accountable as a result of the marketization of the economy and, thus more receptive to technological change, and (2) forcing R&D institutions into economic accountability by drastically constricting their budgets and revenue streams. Budget allocations from the state were, accordingly, reduced, management autonomy of R&D units was increased, mobility of S&T personnel was encouraged, and efforts were made to promote the establishment of a "technology market." Research institutes were expected to enter this market and raise revenues through commercial activities.(14) At the same time, there was a recognition that some forms of research could not be sustained through commercial activities. Responses to this concern included the initiation of various special national R&D programs (discussed further below), and the establishment of the National Natural Science Foundation of China (NSFC), one of the more successful innovations of the reform era.[(15)]

The S&T reforms were very disruptive of the nation's R&D system when first introduced. But, the successful injection of commercial values into the system has forced R&D units to think about their relationships to industry and agriculture in ways that had not been true in the past. In some respects, being "forced into business," diminished the professional standing of scientists and engineers. In other respects, though, it has been enhanced. This is especially true with respect to the increasing involvement of scientists and engineers in decision making about research, including the institutionalization of the principle of peer review in the funding activities of the NSFC and other major national programs.

The linking of centers of research with enterprises through the creation of "technology markets," initially, proved to be more difficult than had been envisioned by the reformers.[(16)] Many research institutes and universities responded to slashed budgets and the uncertain technology market by establishing their own "spin-off," or "new technology enterprises" (NTEs), a move which is one of the more interesting and important unplanned consequences of the S&T reforms. The NTEs gradually led to the legitimization of new commercial roles for research institutes and universities and have helped create a vibrant culture of technological entrepreneurship - typically, absent in the traditional state owned enterprise (SOE) sector - which is becoming an important asset in China's high technology development. Some of China's leading high technology firms, such as Founder and Legend, are spin-offs of this type. And, as Gu Shulin has effectively argued, the NTEs have played a crucial role in reducing cultural and linguistic barriers to the introduction, assimilation and diffusion of modern information technologies.[(17)]

To help promote the formation and viability of NTEs, the state initiated the Torch program in 1988, and sanctioned the establishment of a number of high technology zones to provide a favorable environment for high technology industrial development.[(18)] By 1998, there were 53 nationally sponsored (plus hundreds of locally sponsored) high tech zones at various parts of the country with some 65,000 NTEs registered with them. In 1997, these enterprises spent 216 million yuan, or an average of about 3.9 percent of sales, on R&D, a figure significantly higher than 0.18 percent of sales spend by large- and medium state-owned enterprises.[(19)]

Programmatic Innovations. The reform era has also been characterized by the introduction of a variety of new funding schemes and institutional innovations intended to bring focus and coherence to R&D and technology diffusion efforts. The scope and variety of these during the 6th, 7th, and 8th Five Year Plan periods is evident from Table 2. Of particular note are the National Program of Key S&T Projects (gongguan), and the National High Technology R&D Program ("863"). The former - funded by both central and local governments - is closely linked with national five year economic plans and is oriented towards a range of applied research activities in agriculture, communications and transportation, energy and raw materials, machinery and electronics, environmental protection, public health, population control, etc.

Initiated in March, 1986 on the advice of four senior scientists, "863" has been a relatively well funded, and somewhat successful, effort to monitor the world's high tech frontier, provide training opportunities for a new generation of researchers, and advance Chinese high technology capabilities. It employs expert panels to specify Program priorities and to select specific projects.[(20)] Five fields of research - biotechnology, information technology, energy, and new materials - have been administered by the State Science and Technology Commission (now the Ministry of Science and Technology, MOST), while two others - space and lasers - have been administered by the Commission of Science, Technology and Industry for National Defense (COSTIND). The original budget for the Program called for an expenditure of 10 billion yuan over the period 1986-2000 from a special central government line. During the 1991-95 period, though, actual expenditures were closer to 15 billion yuan. In 1993, ocean technologies were added to the Program, the budget was enlarged, and a new round of projects were initiated.

This proliferation of programs, or "program activism," is partly attributable to competitive bureaucratic entrepreneurship among China's S&T policy officials (who want to be assured of a role in the reformed system), as well as to underlying frustrations with the quality and efficiency of research and innovation practices during the institutional transitions of the reform period. But, as suggested above, they also represent efforts to support new modes of research, development, and diffusion activities in keeping with reform objectives, i.e., the desire to improve the technological bases of the Chinese economy, to link research with production, and to make notable gains in the quality of research by using peer review mechanisms and regular project and program evaluations. In comparison with the pre-reform period, funding for scientific research has become more competitive for individual researchers, but with program activism, funding streams have become more pluralistic. As in other countries, those who can master the competitive grant getting game can find adequate support for their work from these various funding streams. At the same time, there has been concern that program activism tends to disperse research money across too many bureaucratic fiefdoms, leading to less than effective R&D spending.

Assessing the Achievements of the Deng Xiaoping Era.

As the above discussion indicates, the 17 years from the beginning of the Deng era until the end of the 8th plan period in 1995 were filled with many changes in Chinese science and technology. China had succeeded in putting behind it some of the effects of the Cultural Revolution, although the latter's disruption of higher education has left an enduring imprint on the age structure of China's technical community which has yet to run its course.[(21)] The place of science in China's national development strategy had been elevated dramatically and with it the political standing - and to a more limited extent, the economic standing - of technical intellectuals. Tight Party control of scientific institutions had been relaxed, a labor market for scientists and engineers was introduced, and opportunities for a measure of professional self-governance had been expanded.[(22)] In addition, the higher education system was restored and much improved over this period, with regular degree programs for graduate study introduced for the first time.

While subject to wrenching changes in the 1980s, considerable progress had been made in building an infrastructure for domestic research and for participating in international science and technology transfers; China had clearly reached a point where some value - indeed, perhaps quite a lot - could be captured from its participation in global economic and technological processes. Evidence of progress could be had in such diverse measures as published papers and patents, productivity gains, and increases in value added exports. In many cases, the "walking on two legs" strategy succeeded in introducing and indigenizing useful new technologies and technological systems.[(23)] And yet, major problems remained.

First, in the critical area of human resources, the majority - some 200,000 - of the more than 300,000 students and scholars who had gone abroad since the beginning of the reform period had stayed abroad, constituting for - the short to medium terms, at least - a serious brain drain. In the face of an aging technical community, and contrary to the intent of the study abroad policies, this has made it difficult to staff research facilities and university science and engineering departments with a new generation of highly trained personnel capable of providing world class scientific leadership. About half of Chinese scientists were under 35 in 1997, with only a relatively small percentage having a higher than "junior" (eg., assistant professor) rank.

At the same time, about three-quarters of "senior scientists" (full professors, senior engineers) will retire by the year of 2000. China is thus facing a serious shortage of qualified senior technical personnel in the short to medium terms. The situation is exacerbated not only by the "external" brain drain - the loss of technical talent to universities, industry, and research institutes abroad - but also by the loss of technical personnel to foreign invested firms in China (the "internal" brain drain), and the loss of people to careers in science more generally, especially as the brighter and more talented potential scientists seek higher incomes and more comfortable lifestyles in business and finance. Second, in spite of the gains made in revitalizing the R&D system, progress in improving production technologies with imported know-how, and some cases of effectively linking R&D and imported technology (see note 25), the coordination of domestic R&D policies with technology import policies left much to be desired. Technology imports often worked against domestic R&D and against the objective of linking the latter to production; more often than not, enterprises - when they could afford to do so - sought to satisfy their technology needs with imported technology rather than domestic know-how.

This second problem was symptomatic of a third - that of persistent difficulties in forging a national system of innovation.[(24)] For all the strides made during the Deng era, the progress towards such a system tended to be disjointed and quite uneven. While some forward movement in creating incentives for new technologies in state enterprises could be discerned, for instance, the many systemic problems with SOEs precluded most of them from becoming critical parts of an industrial innovation system. At the other end of the research to production spectrum, basic research, and the idea of "quality science," was neglected for most of the Deng era.[(25)] And, in spite of the many new schemes for funding R&D, noted above, funding levels for research and for education were quite low by international standards, and efficient mechanisms for providing venture capital for high risk endeavors were only just beginning. In addition, the various national R&D programs, like the gongguan and 863, while helping to promote research in more effective ways, also had the effect of reinforcing the concentration of applied research in research institutes and universities instead of in industry. Signs of creative technological entrepreneurship in the industrial sector were evident in the NTEs, as noted above, and many of the more successful township and village enterprises (TVEs) also showed an aggressive interest in technological enhancement and innovation (though typically lacking in good technically trained staff). But, the weight of policy - and the direction such weight gave to the flow of resources - was biased more towards SOEs rather than towards these more innovative sectors.

Thus, in spite of much progress between 1978 and 1995, China's readiness to meet the challenges of the new industrial revolution through its reconfigured policies and institutions for research and innovation remained uncertain. Many features of the S&T system needed further reform - in part, because of the successes of earlier reforms - and ongoing rapid technological change in the global economy posed new challenges for Chinese high technology development. And with the surge of foreign investment in manufacturing which began in 1992, the reality of the new industrial revolution acquired a presence on Chinese soil which it had not had before - both threatening the development of indigenous Chinese technical capabilities in new ways, and offering new opportunities. When the 1995 science conference was convened, therefore, hopes that China would be "on the train" as it was beginning to leave the station were commingled with doubts that a seat could be secured.

Towards the 21st Century - "Science, Education, and Sustainable Development"?

In addition to the 1995 "Decision on Accelerating S&T Progress," noted above, elite concerns for preparing China for the knowledge economy are also evident in the treatments of S&T at the 1997 15th Party Congress and at this year's National People's Congress. Key themes which emerge from these meetings, and which shape the latest round of reform and policy change include the following. First, in spite of the ubiquitous verbal support for S&T since 1978, spending for research and education lagged behind, especially when seen in cross-national terms. Hence, the 1995 pledge to increase resources flowing to science and education during the 9th plan period, with a target of 1.5% of GDP set for "gross expenditures on research and development" (GERD/GDP) by the year 2000. Coupled with the commitment to spend more has been a recognition of the need to concentrate resources more effectively in centers of excellence. Second, the perennial "research to production" problem was still a conundrum even though its dynamics had changed as a result of the Deng-era reforms, a changing industrial structure, and the deepening of foreign investment and international economic cooperation. Third, post-95 thinking seemingly is taking the "knowledge" in "knowledge economy" more seriously, with the result that basic research and quality education are receiving some of the attention long denied to them. Finally, in response to the deteriorating environmental conditions China has experienced during the reform period, the theme of sustainable development has entered into the S&T policy discourse as well, and there are signs that China sees its "train" to the knowledge economy as a ride to a green future as well.[(26)] Let us examine some of the policy responses to these conditions in greater detail.

High Level Policy Direction. First, an important institutional innovation of the post Deng period is the (re)establishment in March, 1996 of a high level science and technology policy mechanism at the State Council level.[(27)] Chaired by Zhu Rongji (with Li Lanqing as vice-chair), it is composed of the ministers of the leading science, education, and economic agencies (MOST, SETC, State Development and Planning Commission, COSTIND, the Ministries of Education, Finance, and Agriculture, the Presidents of Chinese Academy of Sciences (CAS) and Engineering (CAE) and a deputy secretary-general from the State Council). The group sets direction for the science and education components of 5 year plans and has made key decisions on the long range S&T development plan to the year 2010. It has also approved the launching of the CAS knowledge innovation program, the initiation of the State Key Basic Research and Development Program (discussed below), a new Education Revitalization Program, and the initiation of new and relatively expensive "big science" projects, such as new astronomy facilities, a synchronous radiation project in Hefei, and an earthquake monitoring network.

R&D Spending. Although Chinese spending on R&D has more than trebled over the course of the 1990s, it has not kept pace with the growth of GDP.[(28)] As a result, the GERD/GDP has remained largely unchanged since 1991.
When China's GERD/GDP is seen in international comparison, it appears rather meager when compared with both the highly industrialized countries and with some of its Asian NIE neighbors.[(29)]

But recognizing the need to increase R&D spending raises a number of interesting science policy issues for China. The first, of course, is whether the 1.5% goal can be reached, and if so, how? If it is reached, will the money be well spent? With the GERD/GDP at only 0.5 or 0.6% in 1995, the prospect of elevating it to 1.5% by 2000 may be unrealistic. And, of course, issues surrounding the GERD/GDP target are not confined to the numbers themselves. As important are issues surrounding the changing sectoral and jurisdictional distributions of R&D funding sources.

It is clear that the central government does not want China to attain the 1.5% objective only through increases in central government S&T expenditures. Instead, it looks to enterprises and to local governments to pick up much more of the load. While expenditures from these sources have increased, the share form enterprises has not changed significantly over the 1990s. As a result, when we look at the sectoral distribution of spending in countries with which China likes to compare itself we see that China's situation remains quite anomalous; whereas the great bulk of R&D expenditures in most market economies occurs in industry, in China, industry still trails behind R&D institutions in a pattern which reflects the enduring influence of the Soviet model.

The issue of whether increased spending will be money well spent, links policy for R&D spending back to the problems of institutional change which system reform efforts have been addressing since 1985. The most dramatic case of a new generation of institutional reform resulting from post-1995 policy thinking is the "knowledge innovation" program of CAS (discussed further, below), where substantial funding to facilitate a radical restructuring of China's premier research institution is to help insure that the impacts of increased R&D expenditures are not dissipated by archaic structures. The problem of "quality spending" also applies to research in industry, where increases in funding are occurring in a very fluid institutional environment, with some enterprises (at least large ones) setting up their own R&D centers, some R&D institutes transforming themselves into enterprises (qiyehua), other R&D institutes spinning off enterprises, and with a growing practice of enterprises contracting out to, or forming other types of technical relations with, R&D institutes and universities.[(30)] As discussed further below, the abolition and/or reorganization of a number of industrial ministries following the 9th National People's Congress in 1998 have further complicated the organizational setting in which research in industry is supported and performed.

In addition to the sectoral and jurisdictional issues involved in increased R&D funding, there is also the interesting emerging issue of foreign support - especially foreign corporate support - for Chinese R&D.[(31)] While seemingly a small share of total national R&D, these foreign expenditures, in strategic terms, are of considerably greater importance. Microsoft's new R&D center, for instance, represents a substantial addition to China's overall R&D effort in software. Foreign firms are typically found in areas of research which are important for China's high technology aspirations and, by their very nature, seek to engage China's best technical talent and productive research enterprises. Chinese R&D can benefit substantially from this type of foreign presence, but there clearly are risks, as well, that the most productive and innovative parts of the system will be captured by foreign interests.[(32)]

Prioritization and Professionalization. Post-Deng science policy and programs include a new emphasis on the importance of prioritization and of concentrating resources based on quality and performance.[(33)] Although China has a vast system of R&D institutions and a very large number of scientists and engineers, the productive ones are in the minority. According to a 1996 MOST report, for instance, as many as 50% of the R&D institutions in China don't publish a single paper in the course of a year.[(34)] China's "effective" research system is thus much smaller than the total number of institutes, and the "effective" research community is similarly much more limited in size than sometimes appears. China has a large number of scientists and engineers in research and development relative to other countries (though not as a percentage of the labor force).

But, when the productivity of this large technical community is considered, China does not fare as well as it might in international comparisons. As Table 8 indicates, for instance, China ranked only 15th in terms of research papers catalogued in the Science Citation Index in 1995 and 7th in the Engineering Index, although some improvement was noticeable by 1997, when China's ranks had increased to 12th and 4th respectively.[(35)]

S&T policy in the post-95 period, thus, has sought to insure that resources flow to those who are producing. The more widespread use of peer review is one mechanism employed for this purpose,[(36)] the diffusion of project evaluation practices in the administration of the state's R&D programs is another, and the designation and special funding of "key" institutions ("key" labs, "key" universities, engineering research centers, etc.) which score high on meritocractic standards is a third. Internationally recognized publications, in most fields, have become the "coin of the realm" during the

1990s, both in competition for promotions and research grants among individuals and in competition for "key" institutional status.

Three other manifestations of this attention to prioritization and professionalization are the introduction of the systems of academicians in the CAS and CAE, various special programs to encourage younger researchers both in China and abroad, and the introduction of programs such as the Cheung Kong professorships (discussed below) which provide special recognition and rewards for excellence. The systems of academicians involve the recognition of outstanding achievements and contributions to Chinese S&T and provides academic leadership opportunities for those so recognized.[37] Programs oriented toward younger scientists are a reflection of the distorting consequences of the Cultural Revolution on the age structure of the research community, and the fact that now some of its better trained and most productive members are those in their late 20s, 30s and early 40s. All of these efforts to reward quality inevitably entail the introduction of elitism, and greater stratification and inequality into the research system.[38]

Stepped Up International Cooperation. Since the beginning of the Deng period, as we have seen, China has sought benefits for S&T development from the international environment and has in many ways been quite successful in doing so. In the early years, it was usually the "student" or junior partner in collaboration. As domestic research and educational quality and technical capabilities have improved, however, China's international S&T relations have become less asymmetrical. Over this period, China has also set up an extensive infrastructure for international cooperation involving professionally staffed policy and administrative mechanisms and dedicated budget lines. As it views the challenges of globalization, China recognizes the need for expanded international involvement and seeks to position itself to take advantage of the trends in international S&T - growing international coauthorship, the importance of international cooperation for "big science," and the changing patterns in the internationalization of corporate research and technology transfer. In all of these areas, "overseas" Chinese scientists and engineers are seen as important resources - part of an "extended" technical community - for successful international cooperation. The "Symposium on the 21st Century China and the Challenges to the Sustainable Development," held in Washington D.C. between September 3 and 5, 1999, represented one such effort in which 34 Chinese professional societies in the United States co-sponsored with the Western Returned Scholars Association in China.

The release of the Cox report, which alleges that China has used its networks of international cooperation for espionage, has required that China reexamine its assumptions about the environment for international cooperation. While the longer term implications of the Cox committee allegations cannot be discerned as of this writing, in the short term, it is likely that China will attempt to strengthen ties with the EC and Russia in the face of the new uncertainties in relations with the US. More generally, though, China appears to be less confidant that the international environment will be as open as it has been, a judgement which is strengthening the voices of those - including CAS president, Lu Yongxiang - urging more self-reliance in innovation and (one suspects) more generous budgetary policies for the support of indigenous Chinese research.[39]

Program Activism for the New Century.

Just as the program activism of the Deng-era illustrated the main thrusts of policy, so the new emphases of policy - especially on the importance of building up a quality research tradition in basic science - are discernible in some of the key programs of the post-Deng period. While these do not necessarily replace programs begun in the 1980s - indeed, some, like "863" have been strengthened and expanded - they do reflect the changing priorities of the late 1990s. Among the more significant are:

The Knowledge Innovation Initiative. In 1997, the Chinese Academy of Sciences launched its most ambitious restructuring since the beginning of the reform era. Supported by a grant of 5.4 billion yuan ($US 650 million) from the Science and Education Leading Group, the CAS "knowledge innovation" program is intended to secure a lead role for the Academy in the transition to the knowledge economy in the 21st century. The grant includes 600 million yuan that is to be used to recruit 200 young scholars from abroad. Reorganization and down-sizing play a key role in the Initiative.[(40)] Selected institutes within the academy will be regrouped into new centers or bases, according to areas of research, in order to overcome duplication and the excessive spreading of resources.[(41)]

In an especially interesting case of restructuring, the Legend Group, China's largest computer maker, and originally a "spin off" from the CAS Institute of Computing Technology, has now annexed its parent institute, taking in its staff, patents, property, and equipment with the intent of reconfiguring these as its corporate research center. By reducing the staff to 100 from the original 1,500, the average per capita research expenditure will rise from the current 20,000-50,000 yuan range to 200,000-400,000 yuan. Legend will operate as a share-holding corporation, having its own board of directors, with 35 percent shares held by its employees, 35 percent by CAS, and the remaining sold to the public.

The State Key Basic Research and Development Program. A second important programmatic initiative is the State Key Basic Research and Development Program, which seeks to build up the nation's capacity for original knowledge generation and, again, to concentrate resources with people of excellence.[(42)] The Program, which began in 1998, calls for the channeling of some 2.5 billion yuan ($300 million) over five years through MOST to support some 50 projects at an average level of 50 million yuan ($6 million) per project.

While there has been general agreement in China in recent years about the need for more "basic" research, there has also been some disagreement within the scientific community about the meaning and purposes of basic science. Some have argued for the importance of curiosity-driven approaches, closer to the idea of "pure science," while others have supported mission-related, "strategic," or "oriented-basic" research of relevance to the country's social and economic development. The latter, apparently, has carried the day since the Program has only accepted applications for projects falling within six broad areas of national priorities - population and health, information, agriculture, resources and the environment, energy, and new materials - specified by MOST.[43] The first ten projects got funding in February of 1999, and the second round of proposal evaluation has been under way.

The Cheung Kong Scholars Program. A final example of a program representing post-1995 policy themes is the Cheung Kong ("Changjiang," or Yangtze River) Scholars Program. In keeping with the theme of kejiao xinguo, the Ministry of Education has launched an "Education Revitalization Plan toward the 21st Century" which was approved by the State Leading Group on Science and Education in 1998 and which included the Cheung Kong Program. Launched in August 1998 with an initial donation of 70 million Hong Kong dollars ($US 9.5 million) from Li Kai-shing's Cheung Kong Infrastructure Holdings, Ltd., and with matching funds from MOE, the Program supports prizes for distinguished achievements[44] and a series of endowed professorships for outstanding young and middle-aged scientists (usually under the age of 45) residing either in China or abroad.[45]

The search for the first round of Cheung Kong professors started in November 1998 when MOE received 687 applications for the positions from 139 universities and selected 148 of these from 63 universities. The openings were then advertised through the nation's media and the Internet. More than one half of the applications came from scientists of Chinese origins who were working abroad, including tenured professors, Presidential Fellows in the United States, and senior researchers at Intel Company. Of the over 50 scholars who applied for the nine positions at Beijing University, for example, most are now working abroad. While the stipend for the professorship is significantly higher than the ordinary salary in China, it is quite low for those overseas.[46] Thus, the considerable interest shown in the Program by expatriate Chinese is probably more a reflection of a desire to contribute to Chinese development, and to make contacts with a new generation of Chinese students, than of any pecuniary considerations.

As of this writing, two rounds of recruitment have occurred, resulting in the endowment of 450 positions at 112 universities. Of these, half are concentrated in 26 institutions.

While one of the objectives of the Program is to mitigate the effects of the brain drain by building bridges between Chinese institutions and outstanding Chinese researchers working abroad, complaints are sometimes heard from scientists based in China that the four month annual stay at a Chinese university which is required by the Program can make only a limited contribution to the development of Chinese science. Support for expatriate scientists, therefore, is not always regarded as the best use of resources. There are also complaints that the selection process considered too much the balance of numbers of Cheung Kong Scholars in each university; as a result, the selected universities and disciplines may not be the strongest.

Supporting the Innovators.

Since the beginning of the reform era, an underlying question for the success of reforms has been the extent to which those who creatively exploit the new opportunities offered by the reform environment are rewarded with the sanction of state policy. In the areas of science and technology, this question has often applied to the innovators - those who effectively transcended bureaucratic obstacles and organizational boundaries to bring together the assets of the research community, industry, trade, finance, and marketing, etc. to employ knowledge in products and processes in new ways. As noted above, while policy declarations often supported these activities, the weight of policy - in expenditures, in the inertia of old regulations, etc. - often favored the status quo.

This has been especially true with regard to many of the NTEs, and to those in universities and research institutes who are keen on transferring research results to commercial uses, but who have had to endure positions subordinate to traditional state institutions with regard to access to financial resources and some regulatory benefits. A series of recent policy changes are intended to create a more innovation friendly environment for such innovator-entrepreneurs by addressing some of the problems they face. These measures grow out of an increasingly sophisticated understanding of innovation issues on the part of senior policy analysts and policy makers.

New Attention to Innovation. Chinese thinking about technological innovation has changed dramatically since the beginning of the reform era when western concepts of innovation, based on the operation of a capitalist economic system, were quite foreign. China has followed a steep learning curve since then, and by the late 1990s, Chinese thinking seems to be converging with conceptions of innovation found in the OECD countries. These include an appreciation for multiple routes to innovation, the importance of the idea of an innovation system, and the related notions that the non-research parts of the system affecting the demand for new knowledge (as well as its supply), and the ways that the risk-reward equation of innovation is managed, can be as important as the results of R&D.[(47)]
Less clear, though, is whether new ideas about innovation can be effectively introduced to the institutions of the industrial economy which have for so long resisted them, and whether the right balance can be found between new market-driven approaches to innovation vs. state interventions to support national R&D programs.[(48)] The answer, one suspects, is to be found in the interactions between new programmatic initiatives from the top,[(49)] and "bottom up" demands for technological change from the more innovation oriented society which has resulted from economic reforms and the open door.[(50)] In both cases, important questions include the nature of incentives for innovation activities, the nature of the efforts made to build innovative capacity in enterprises, and the types of interorganizational relations enterprises maintain with research institutions and universities.[(51)]
Recent policy decisions address these.

Lubricating the Research to Production Mechanisms. In spite of years of policy initiatives and exhortations intended to facilitate the transfer of research results to commercial use, a number of obstacles have remained. Among these have been the problem of placing a value on technical knowledge, ambiguities about the assignment of property rights to discoveries and inventions (and rights to appropriate profits from these), and the persistence of disincentives and other barriers to the easy movement of people, as the possessors of tacit knowledge, from research to production settings. Interesting new approaches to the alleviation of these problems have appeared in April, 1999, when the State Council gave its approval to the "Several Provisions on Promoting the Transformation of Scientific and Technological Achievements," which had been prepared by an inter-agency team from MOST, the Ministries of Education, Personnel, and Finance, the People's Bank of China, the State Administration of Taxation, and the State Administration of Industry and Commerce.[(52)] The "Provisions" make relatively generous allowance for rewarding the discoverers of new, commercially useful knowledge, both in terms of direct compensation and in terms of the value of an idea as an equity contribution to a new enterprise. They also attempt to untangle the often complex ownership issues which arise when new high tech firms are spun off from state research institutes and universities, spell out more clearly the limits to collective claims on the benefits from an innovation, and make it easier for research personnel to move back and forth between the two worlds of research and business.

Funding. To deal with the problems occasioned by an underdeveloped venture capital market, the State Council in June, 1999, also approved the trial initiation of a new one billion yuan ($US 120 million) Technology Innovation Fund which is focused on the needs of the roughly 70,000 companies which qualify as "small and medium sized technology-based firms." Firms "...within every frame of ownership" will be eligible for support, with priority given to those with "...independent property rights, high technology, high value-added products and those which are export oriented." In addition to the one billion yuan budgeted, the managers of the Fund hope to leverage additional monies from commercial banks through the subsidization of interest rates.[(53)] There have also been reports that MOST has joined with the Ministry of Foreign Trade and Economic Cooperation in creating support policies designed to boost China's high technology exports from 6% of total exports in 1999 to 14% in 2002.[(54)]

Problems and Prospects.

In many respects, the changes seen in Chinese S&T policy and in the S&T system over the past 20 years are truly remarkable. And, however disruptive they may have been, when the last 20 years are viewed against the last 100, these past two decades have been among the more stable Chinese science has experienced this century. China thus faces the new millennium from a much stronger position than anyone might have expected in 1978. Indeed, one could go on to discuss additional achievements and positive developments. The rapid growth of the Internet in China, for instance, is - as elsewhere - revolutionizing the ways Chinese researchers work and is "informaticizing" society in many ways which are consistent with the development of a knowledge economy.[(55)] At the same time, the outside world has also changed, perhaps faster than China itself in some areas, as implied by our departing train metaphor. The challenges of "catching the train," thus, have not subsided; the more critical of these include the following.[(56)]

Manpower. In addition to the problems with the numbers and productivity of scientists and engineers noted above, there are also problems with the distribution of manpower. Too few high quality S&Es are in industry, and too many in R&D institutes. The radical changes proposed for CAS in the knowledge innovation initiative are symptomatic of the problem; it has also been announced that radical restructuring and reductions in personnel along the lines of the CAS will be forthcoming in a large number of ministerial research institutes in the near future as well, especially in light of the major governmental reorganizations which have occurred since 1998. For instance, it was recently reported that 242 institutes affiliated with 10 bureaus (former industrial ministries) of the State Economic and Trade Commission (SETC), will undergo major reform.[(57)] But whether the major downsizing of CAS and ministerial research institutes will lead to the productive reemployment of laid off research staff in industry remains to be seen.

Expenditures. As we have seen, although expenditures of S&T have gone up in recent years, by most measures, Chinese research is still seriously underfunded by international standards. This clearly affects the manpower problems, above, especially the brain drains, and by allowing a "culture of scarcity" to persist, also may affect the building of a quality research tradition, as noted below. As with manpower, funding problems also have distributive and quality dimensions. That is, while there is a need for significantly more spending (if the GERD/GDP, for instance, is to approach the norms of the industrialized countries), the questions of "who spends how much, on what, and of what quality?" still have to be resolved. The effort to shift a large share of the nation's R&D support to industry (and local government) is having some effect, but China's spending patterns are still far from the norm of the industrialized countries, as we saw in Table 6. But getting industry to pick up a significantly greater share is not simply a matter of "policy push." Industry will have to see the benefit from doing so, and that will require a change in industry incentives (which seemingly is occurring) and the development of a strong and effective tradition of enterprise-based industrial research (which is just beginning).

A Quality Research Tradition. The themes associated with kejiao xinguo, especially the new emphasis put on basic science and "knowledge innovation," raise interesting questions about China's research practices and the building of a research tradition of quality. Given the disruptions in science and education during the Maoist period, and given the strong commercial values which have influenced the academic community during the reform period, it is not clear that China has had the opportunity to build a quality research tradition based on scientific values. In recent years, reports of serious cases of scientific fraud have sharpened this concern for standards.[(58)]

As noted above, the new emphasis on professionalism carries with it the wider use of peer review and project evaluation. Yet, quality concerns continue to surface. Within China, some have observed that for all the attention given to science in the post-Mao period, the actual achievements - especially in comparison with earlier years - have been modest. From knowledgeable observers abroad, one hears that in spite of improvements brought about by the introduction of peer review mechanisms, the project selection process does not always lead to first rate research. The pool of experienced scientists capable of providing leadership is too small, in this view, with the result that peer review often lacks anonymity, and judges in the process too often have interests in the outcomes of the reviews. In addition, there seems to be a bias toward selecting senior people (who may have fallen behind the research frontier) for program design and project selection processes, with the result that some of the younger people who are closer than their elders to the leading international work do not have the opportunities they should to shape the nation's research agenda. This in turn affects China's international scientific cooperation objectives. China becomes interesting to international science less for the quality of its research than for the quality of its students and young scientists who become candidates for recruitment into research activities performed or controlled from abroad.

Science policy leaders are clearly aware of the problem and, characteristically, perhaps, seek to remedy it with new national programs. The new State Key Basic Research Program, for instance, has generated hopes that it will set new standards of quality and perhaps produce China's first Noble Prize. Those who favor the more curiosity-driven approach, however, regard the Program as short-sighted and not good for building a quality research tradition. In addition, although the initiation of the Program was intended to provide more substantial grants for basic research, concerns have been expressed that the impact of the large grant is being watered down through the support of a series of smaller sub-projects out of the budgets for the main project.

The "Baiqianwan" Program ("100, 1,000, 10,000"), begun in 1997, aims to produce 100 young scientists by the year 2000 who are working at the world's research frontiers, 1,000 who are recognized internationally as leaders in their disciplines, and 10,000 whose work is generally up to international standards. And the NSFC Outstanding Young Scientists Fund - begun in 1994 and modeled on USNSF's Presidential Fellowship Program - has thus far supported 426 top scientists under the age of 45 years old. Awardees are selected based on past performance, and are given 600,000 yuan for a three-year term. Among them, 80% have studied or conducted research abroad, four have been elected to CAS or CAE, four have been selected as chief scientists of the State Key Basic Research and Development Program, and more than half of the newly appointed Cheung Kong Scholars have been recipients of the Outstanding Young Scientist award. Apparently impressed by the achievements of this program, Zhu Rongji approved an increase of the amount of money allocated to the Fund to 180 million yuan in 1999 from 70 million yuan in previous years, which will result in an increase of the strength of the funding and/or an increase of the number of awardees.

While such programs are having positive effects, and additional "untied" material resources from the state could soften the negative influences on quality which have developed during the reform period as result of excessive commercialism, emphasis on applications, and the short term thinking these engender, it remains to be seen whether matters of quality can be fully addressed through policy and national programs alone. A more difficult and subtle matter - the internal governance of science and its relations to the state and, increasingly, to industry - may be of greater importance. Here, the attitudes of the technical community, and of the state, towards autonomous academic governance are likely to be determining. And while there is evidence of positive change in those attitudes, there is also considerable ambiguity about how they will affect the shaping of a research tradition.[(59)]

Thus, it remains to be seen whether China will be "on the train" to the new industrial revolution. It has certainly prepared itself in important ways, under great difficulties, to do so. Yet doubts clearly remain, especially when we consider such complex issues as professional governance and China's capacity for building the kind of "culture of innovation" which helps define the "knowledge economy."

Social Capital - The "Ticket to Ride?"

Efforts to understand what makes a culture of innovation start with the recognition that while new knowledge is important for innovation, so are human motivations and the incentives which influence people to assume the risks of innovation. Institutional arrangements, such as strong IPR systems and venture financing mechanisms for high risk, high reward undertakings, clearly help structure the motivational environment. We are also coming to better appreciate that to "capture value" from innovation requires that various "assets" - technological, managerial, financial, etc. - which "complement" each other, be mobilized and integrated.(60) It is becoming increasingly difficult for any one firm (or nation) to possess all the knowledge, market acuity, financial resources, and managerial or manufacturing assets to sustain and capture value from innovation on a regular basis. Collaboration and "partnering" with other firms (and with government bodies and universities) has therefore become common among successful players in the innovation game. This, in turn, has called attention to the conditions under which cooperation is possible and works best, especially with regard to the costs and speed of transactions. For some, the concept of "social capital" has emerged as a useful tool for explicating these questions about cooperation.

Social capital has been defined, variously, as "...the 'stock' that is created when a group of organizations develops the ability to work together for mutual productive gain,"(61) or in Robert Putnam's terms, as those "...features of social organization, such as networks, norms, and trust, that facilitate coordination and cooperation for mutual benefit."(62) Like other forms of capital, social capital "...accumulates when used productively."(63) If innovation, and the appropriation of value from innovation, involves the efficient accumulation and combination of technological and institutional assets which are "complementary," than being "rich" in social capital, i.e., in networks of trust to supply new knowledge and facilitate transactions,(64) will allow for the rapid mobilization of these "assets" in ways which will reduce the costs of the transactions necessary for doing so. Studies of the biotechnology industry in the US, and of such "learning regions" as Silicon Valley, point to rich endowments of social capital which continue to grow through successful cooperation.(65)

Introducing the concept of social capital at this point in the discussion invites more questions than it answers. Is the close association which is thought to exist between social capital and a culture of innovation really more than accidental? If yes, how would we assess China's stock of social capital and the conditions in China for expanding it? Does the abundant evidence supporting the idea of China as a "low trust" society justify a conclusion that the prospects for building social capital are less than bright? Or, should we view such phenomena as the successes of the new technical entrepreneurship, the improving relations among universities, research institutes, and enterprises, and the ability to execute complex national R&D projects as signs that China, after 20 years of reform, is better endowed with social capital than we had been led to believe?

Attempts to answer such questions, inevitably, will also lead us to consider the stock and growth of social capital in relation to broader issues of the political economy - the latter's ability to manage the tensions between innovative sectors of the society and the nation's welfare responsibilities, its approaches to providing predictability in social relations in the face of a weak tradition of law, and its frequent shifts between shou and fang - the alternative tightenings and relaxations of social control strategies - which have made long term perspectives on trust building and cooperation difficult to sustain.

A social capital perspective on the creation of "the knowledge economy" in China does not diminish the importance of the types reform measures and aggressive programmatic initiatives for the support of research and innovation we have examined here. Instead, with reference to the broader political and economic systems, it asks whether these policy measures promote or erode trust and possibilities for cooperation. Since S&T reforms and technological enhancement programs have proceeded over the past 20 years without any formal "social capital impact statements," much remains to be done before a full accounting of China's readiness to "catch the train" can be rendered with confidence.

Notes

1 . Cf., Sylvia Ostrey and Richard Nelson. Techno-Nationalism and Techno-Globalism: Conflict and Cooperation. Washington. Brookings Institution, 1995; "Make Better Use of the Globalization Process." Editorial, *China Daily*. November 7, 1998. p. 4.

2. For a useful discussion of some of how new technologies get combined into innovative weapons systems and war fighting possibilities, see Kosta Tsipis. *New Technologies, Defense Policy, and Arms Control*. New York. Harper & Row, 1989. Chs. 1-3.

3. While the extent of change in these assumptions is profound and extensive, it must also be kept in context. Old attitudes and structures persist and, as discussed below, remain targets for new rounds of reform policies. In addition, certain practices from the Maoist period, especially high priority national research and development projects in support of strategic weapons systems, are regarded by some members of the technical community as valued legacies which illustrate how S&T development should proceed. See, Evan Feigenbaum. *The Military Transforms China: The Politics of Strategic Technology from the Nuclear to the Information Age*. Unpublished Ph.D. dissertation, Department of Political Science, Stanford University, 1997.

4. See, Richard P. Suttmeier. *Science, Technology and China's Drive for Modernization*. Stanford, CA. Hoover Institution Press. 1980, and Gu Shulin. China's Industrial Technology: Market Reform and Organizational Change. London and New York. Routledge, 1999. Pp. 12-16.

5. Denis Fred Simon. "China's High Tech Thrust." *China Economic Review*. Vol. 1, No. 1 (Spring, 1989). Pp. 73-92.

6. See, Li Cheng and Lynn White. "The Fifteenth Central Committee of the Chinese Communist Party: Full-Fledged Technocratic Leadership and Partial Control by Jiang Zemin." *Asian Survey*. XXXVIII, 3 (March, 1998). Pp. 231-265.

7. An English version of the Decision can be found in Foreign Broadcast Information Service, Daily Report (FBIS-CHI-95-109), June 7, 1995. pp. 20-31. Preparations for the Conference and the Decision included a frank 400 page policy analysis, "Science and Education for a Prosperous China," prepared by the State Science and Technology Commission for senior Party and government officials. Translated excerpts from this report can be found on the US Embassy, Beijing website at www.usembassy-china.gov/english/sandt/.

8. The four national science conferences held since 1949 - 1978, 1995, along with the conferences on intellectuals held in 1956 and 1962 - are viewed in the Chinese technical community as key events in the chronology of scientific development. In each case, the Party leadership identified itself with S&T and introduced new programs and material support for science and technology.

9. For an excellent study of how the Maoist era term, "walking on two legs," can be applied to the post-Mao period, see Xiaobai Shen. *The Chinese Road to High Technology: A Study of Telecommunications Switching Technology in the Economic Transition*. New York. St. Martin's Press, Inc., 1999.

10. For a useful review of this experience, see Charles Feinstein and Christopher Howe (eds.). *Chinese Technology Transfer in the 1990s*. Cheltenham, UK. Edward Elgar Publishing, Inc., 1997. Chs. 4, 5, 7, 8, 10. The $US 70 billion figure is cited in Ch. 7, Jiang Xiaojuan. "Chinese Government Policy Towards Science and Technology and Its Influence on the Technical Development of Industrial Enterprises." p. 144.

11. Gu Shulin. *China's Industrial Technology*. p. 9.

12. Feinstein and Howe. *Chinese Technology Transfer*. See also, Daniel H. Rosen. Behind the Open Door. Washington. Institute for International Economics. 1999.

13. In 1997, university based researchers received almost 71% of NSFC grants and accounted for almost 64% of domestically published and 71% of internationally published papers. State Science and Technology Commission. *China Science and Technology Indicators, 1998*. Beijing. Scientific and Technical Documents Publishing House, 1999. pp. 79, 193-4.

14. For an insightful recent treatment of the S&T reforms of the 1980s (and their consequences), see Gu. China's Industrial Technology. Part I. See also, International Development Research Center (hereafter, IDRC). *A Decade of Reform: Science and Technology Policy in China*. Ottawa. IDRC, 1997.

15. Since its establishment in 1986, the NSFC has supported three categories of research projects - investigator initiated, "general" (mianshang), "key" (zhongdian), and "major" (zhongda). In its 13-year existence, it has funded more than 50,000 general research projects, 779 key projects, and 166 major projects, expending more than 4.5 billion yuan. During 1996-97, the average size of awards for general projects was 114,000 yuan ($13,800) for three years. The average awards for key and major research projects were, 790,000 yuan ($95,000) for three years, and 4.5 million yuan ($540,000) over five years, respectively. In 1998, the NSFC made awards totaling 837 million Renminbi yuan ($100 million), a notable gain from the 80 million yuan ($21 million) dispensed during its first year.

16. Often the technology to be transferred was not appropriate, the enterprises were not prepared to receive it, and the institutions for market exchanges in technology - such as contract law and intellectual property protection - were underdeveloped at the time. See Gu. *China's Industrial Technology*, p. 25.

17. Gu. *China's Industrial Technology*. Ch. 11. In addition to Gu's important work, for another excellent recent discussion of NTEs, see Lu Qiwen. China's Leap into the Information Age: Innovation and Organization in the Computer Industry. (Oxford University Press, forthcoming). For a comparison of how NTEs have fared in Shanghai, as opposed to Beijing, see Adam Segal. "Constructing High Technology Industries in Beijing and Shanghai." Paper presented to the annual meeting of the Association for Asian Studies, March 11-14, 1999. For an early examination of the significance of the NTEs, see Richard P. Suttmeier. "Laying the Corporate Foundations for China's High Tech Future." *The China Business Review*. July-August, 1988. Pp 22-25.

18. The reasons for, and the evolution of, the Torch Program are complex. The prime motivation was the commercialization of research results. At the time (1988), this included, especially, the results of the newly initiated National High Technology ("863") R&D Program (discussed below). But this was also the time when the NTEs were gaining political legitimacy, and were being seen as useful organizational innovations in response to the "research to production" problems of reform. Torch quickly became associated with the creation of high technology zones and incubators to help support the NTEs which, in the late 1980s and early 1990s, typically lacked commercial acumen and managerial know-how. Cf., Gu. *China's Industrial Technology*. pp. 35 ff.

19. NTEs employed more than 3.15 million persons outside the state enterprise sector. In 1997, they had revenues totaling 556 billion yuan, with 857 enterprises having annual revenues of 100 million yuan or more. *Renmin Ribao* (People's Daily), Overseas Edition, July 30, 1998, p. 2.

20. Feigenbaum argues that the design and administrative arrangements of 863 are derived from the strategic weapons programs of the pre-reform era. This is not surprising given that so many of China's senior research personnel, especially in the physical sciences and engineering, spent most of their careers in the strategic programs. But 863 is also a reflection of the issues of contemporary research policy and S&T reform as well as the influence of foreign models of research administration. Cf., Feigenbaum, *The Military Transforms China*. Ch. 8.

21. It is well to remember that Chinese R&D was not without its achievements in the Maoist era, especially in high priority strategic weapons programs. For some, this experience continues to offer inspiration for how China's S&T activities should be organized. See, Feigenbaum. *The Military Transforms China*. In the aftermath of the bombing of the Chinese embassy in Belgrade and the release of the Cox report, the experience with the strategic weapons programs is again being celebrated. See, for instance, Zhang Jingfu. "Recollections of the Chinese Academy of Sciences and the Development of the Atomic Bombs, Guided Missiles, and Artificial Satellites." Beijing *Xinhua Domestic Service*, May 5, 1999. In *FBIS-CHI-1999-0512*.

22. See, Cao Cong and Richard P. Suttmeier. "China's Brain Bank: Leadership and Elite in Chinese Science and Engineering." *Asian Survey*, Vol. XXXIX, No. 3 (May/June, 1999), pp. 525-559.

23. Recent research has illustrated the payoffs in technological progress when imported technology has been used to complement domestically developed technology, and/or when domestic R&D programs can be harnessed to help indigenize foreign technology. For a detailed study of telecommunications switching technology, see Shen. *The Chinese Road....* See also, Lu, *China's Leap...*, especially his discussion of the Founder Corporation, and IDRC. A Decade of Reform, especially, p. 98 for an account of the merging of a Chinese developed computer-integrated manufacturing system (an 863 project) with advanced imported machine tools.

24. Cf. IDRC. *A Decade of Reform*, especially Chs. 3 & 5.

25. See, for instance, the interesting discussion in Chen-Lu Tsou. "Science and Scientists in China." *Science*. V. 280 (24 April, 1998). Pp. 528-529.

26. This topic warrants a separate paper, but it is worth noting here that S&T policy overlaps with

sustainable development concerns in at least three areas. First, the general area of environmental sciences is getting renewed attention, sparked both by domestic needs for better understandings of resources and eco-system processes and by international global change initiatives. Second, China's need to confront the problems of sustainable agriculture seem to be tied to a strategy of increasing the knowledge intensity of agriculture. Third, western themes of "industrial ecology" and "green production," involving the uses of new technologies to achieve dramatic energy and materials savings, are consistent with the structural principles of the knowledge economy. See, for instance, "Trade Commission to Launch Clean Production Plan." Beijing, *Xinhua*, May 14, 1999. In *FBIS-CHI-1999-0514*.

27. While Li Peng was still premier, this mechanism was called the "Science and Technology Leading Group." Under Zhu Rongji, the group's name was changed to the "Science and Education Leading Group" (as befitting the new emphasis being given to education), and it appears to have become considerably more active - meeting 3-4 times per year - and important.

28. According to the latest S&T Indicators report, real growth from 1991 to 1997 has averaged 10.1%, while the growth of GDP has averaged 10.9%. State Science and Technology Commission. *China Science and Technology Indicators*, 1998. p. 44.

29. While the quality and quantity of Chinese S&T statistical data has improved notably in recent years, inconsistencies among different sources remain troubling, as in the expenditure data for 1996 found in Tables 4 and 5. The 40.47 billion figure in Table 4 is probably more reliable than the 33.20 in Table 5 by virtue of being more recent and, thus, more inclusive of reports of actual spending for the year in question.

30. Cf., Gu. *China's Industrial Technology*; See also, Steven White and Xielin Liu. "Organizational Processes to Meet New Performance Criteria: Chinese Pharmaceutical Firms in Transition." *Research Policy* 27 (1998). Pp. 369-383, and Richard P. Suttmeier. "Emerging Innovation Networks and Strategies for Industrial Technology in China: Some Observations." *Technology in Society*. Vol. 19, # 3/4 (August/November, 1997). pp. 305-324.

31. Systematic information on these new endeavors is still lacking. While a large number of firms seem to be supporting some applied research and technical service work to support local manufacturing and marketing, either voluntarily or to satisfy Chinese offset requirements, those supporting Chinese R&D as part of their own overall corporate technology strategy seem to be more limited. These would include Microsoft, IBM, Intel, Motorola, Nortel, Siemens, Ford, GM. For a brief but useful discussion, see Marco Di Capua. "Technology Innovation in China." *The Bridge*. Vol. 28, No. 2 (Summer, 1998). Pp. 9-10.

32. An interesting recent example of this concern is the entry of Microsoft as a member of the Chinese Digital Industries Alliance, a group of leading Chinese IT firms committed to advancing the Chinese IT industry. There has been considerable resistance to the inclusion of foreign firms, even though a number of them have sought membership, but Microsoft's importance, as well as the terms of the Alliance's bylaws, made it impossible to exclude it. See, electronic report in chinanet@sdsc.edu, August 31, 1999.

33. See, for instance, "China Doubles Budget to Create Astronomy Megainstitute." *Science*. 284 (14 May, 1999). Pp. 1094-5. The themes of priority setting and resource concentration are reflected in President Jiang Zemin's phrase, you suo wei, you suo bu wei ("doing what we need and attempting nothing where we do not"). This phrase is taken from a section of Jiang's report to the Fifteenth Party Congress which reads, "We should formulate a long-term plan for the development of science from the needs of (the) long-range development of the country, taking a panoramic view of the situation, emphasizing key points, doing what we need and attempting nothing where we do not, strengthening fundamental research, and accelerating the transformation of achievements from high-tech research into industrialization." (Emphasis added). Cited in National Natural Science Foundation of China. *Guide to Programs, Fiscal Year, 1998*. Beijing. Military Medical Science Press, 1998. p. vii.

The value of strategic focus and prioritization is also reflected in the principle of wenzhu yitou, fangkai yipian ("anchor one end, free up the other") which attempts to redefine the role of the state in the support of research - a radical reduction of the traditional role of supporting applied research and development in industry and a more concentrated focus on those areas of science most subject to "market failures" - basic research, education, "precompetitive" R&D, and research for "public" missions.

34. Hong Kong *Ta Kung Pao* 1 November, 1998. p A2. In FBIS-CHI-98-312 (8 November, 1998).

35. Chinese authored papers appearing in international citation indices are a small percentage of the total number of papers appearing in domestic journals. Between 1991 and 1997, the latter increased from 94,435 to 120,851. Those catalogued in an international index during the same period rose from 13,542 to 35,300. State Science and Technology Commission. *Science and Technology Statistics: Data Book, 1997*. Beijing. SSTC, 1998; State Science and Technology Commission. China Science and Technology Indicators, 1998. pp. 12, 4.

36. For a recent discussion of peer review practices, see "Breaking the Iron Test Tube: Peer Review and the National Natural Science Foundation of China." US Embassy, Beijing website at www.usembassy-china.gov/english/sandt/. May, 1999

37. Cao and Suttmeier. "Leadership and Elitism...."

38. In some cases (eg., some of the reactions to the CAS knowledge innovation program, which is biased towards outstanding younger people) there has been resentment of these changes; in others, the special material rewards from meritocractic recognition have been refused by recipients, suggesting that a culture of egalitarianism may still be strongly rooted in the research community.

39. Liu Hong. "Academician Stresses Technological Innovation." Beijing, *Zhongguo Xinwen She*. June 18, 1999. In *FBIS-CHI-0621*.

40. The reorganization will focus on changing old management mechanisms and raising efficiency. CAS is to become more open, competitive, and its staff, more mobile. It is expected that the number of fixed positions will be reduced from the current 68,000 to 30,000 by 2010. Individual scientists will be evaluated to see whether they remain qualified to work in CAS, with the goal of reserving sixty percent of the positions for those under 45 years old. New positions will be set according to research needs and will be filled by personnel recruited through open competition who will be subject to competitive tenure review once hired. CAS plans to reduce the number of its research institutes from 120 to 80, and lower the average number of researchers per institute to 200 - 300 (some of the larger institutes currently have more than 1000). By decreasing the number of employees, it will be possible to increase significantly the salaries and levels of research support for the researchers who remain.

41. In the case of the new Academy of Mathematics and Systems Science (which involves the consolidation of four separate institutes), for instance, only 60 of the original 166 researchers were retained. At the same time, the new academy expects to increase the number of doctoral students, post-doctoral fellows and visiting scholars. Three of the institutes involved - Mathematics, Applied Mathematics and Systems Science - are located in the same building. Reportedly, they acquired their separate identities - the latter two were spun off from the Institute of Mathematics - as a result of irreconcilable conflicts among leading mathematicians during the Cultural Revolution (conversation with a historian of Chinese mathematics, Los Angeles, February 1997).

42. The program was first suggested during the NPC and CPPCC sessions in March 1997 by scientist-deputies who were lobbying for increases in the state's expenditure on R&D, hence, it was originally known as the "973" - or March, 1997 - program. One should note that "lobbying" of this sort is a measure of the more effective political participation enjoyed by elite scientists as a result of the reforms. This subject is explored in greater detail in Cao and Suttmeier. "Leadership and Elitism..."

43. The project selection process for the Key Basic Research Program involves proposal solicitation, the convening of a series of peer review committees for the six areas, and the appointment of an expert selection panel composed of 19 scientists - including 15 academicians from the Academies of Sciences and Engineering. The latter was chaired by Zhou Guangzhao, himself a CAS academician,

former CAS president, and now NPC vice chairman. The proposals were expected to identify subjects at the frontiers of research, requiring expanded knowledge of fundamental principles, which would also be of interdisciplinary significance. After several rounds of review, 15 projects were selected in 1998 from 207 proposals by the 19 members of the expert panel. For each project, MOST appoints a chief scientist - who normally must be no older than 60 - who then has authority for deciding the direction of the project and the responsibility for administering budgets and personnel. *Beijing wanbao* (Beijing evening news), January 26, 1999, p. 1.

44. In the first round of prizes, one first class award of 1 million yuan and three second class awards of 500,000 yuan were made.

45. The professorship allows for concurrent appointments at a foreign institution as long as the appointee spends at least four months each year working in the Chinese university. Professorships are awarded to universities who then have the primary responsibility for filling them. Individuals can apply directly to a university for the position. The university then evaluates the credentials of applicants, solicits opinions from three or more Chinese and foreign scholars, and recommends candidates to MOE. The MOE then organizes its own peer review panels, and makes a final decision.

46. The appointment to a Cheung Kong professorship carries an annual stipend of 100,000 yuan ($12,000) over five years in addition to the regular salary, benefits, and housing provided by the universities that make the appointment. During the first three years of their tenure, the professors are required to teach courses in their fields of research, lead important national research projects, and help organize new research teams. Successful performance of these tasks can lead to a renewal of the appointment for another two years. Besides providing capable assistants, universities are also expected provide additional research support. It is expected that about 1,000 such positions will be created within three to five years.

47. See, for instance, Shi Dinghai and Liu Xielin. "Building a State Technological Innovation System Oriented Toward the 21st Century." *Qiushi* # 10 (May 16, 1999). Pp. 22-24. In FBIS-CHI-1999-0615.

48. Uncertainty about where that balance is to be found characterizes research and innovation policies in all countries, of course, but may be especially elusive in today's China. See, Shi and Liu. "Building a State Innovation System..."

49. For instance, the 15 year, State Economic and Trade Commission (SETC)-Ministry of Science and Technology (MOST) technology innovation Program, initiated in 1996, which supports 500 innovation projects in 1000 key enterprises, and the system of engineering research centers which has emerged since the early 1990s.

50. Positive signs that top down initiatives are articulating with new energies from below are found in the institutional innovations in the R&D system which are prerequisites for the effective linking of research and the economy. See, Gu. *China's Industrial Technology*.

51. Cf., White and Liu, "Organizational Processes.... "

52. An English text of the "Provisions"can be found in "Provisions on Transforming S&T Results." Beijing, *Xinhua*, April 20, 1999. In *FBI-CHI-1999-0428*, April 29, 1999.

53. See, "Deng Nan Establishes Fund to Beef Up High-Tech Ventures," Beijing, *Xinhua*, June 25, 1999, In *FBI-CHI-1999-0625*.

54. Stratfor Asian Intelligence Center. Reported electronically in www.stratfor.com/asia, July 28, 1999.

55. According to a recent report from Network Solutions Inc. (NSI), China has moved ahead of the Netherlands, Hong Kong and Japan to move into the top 10 countries (after the US) in domain name registrations for .com, .net and .org. The U.S. still leads in domain name registrations, accounting for about 73% of all registrations for the three names. Following the United States, which had 4.2 million registrations as of the end of March, the top 15 countries (areas) in .com, .net and .org registrations are as follows:

1. Canada
2. United Kingdom
3. France
4. Germany
5. Sweden
6. Spain
7. Italy
8. China (Mainland)
9. Australia
10. India
11. The Netherlands
12. Korea
13. Hong Kong
14. Japan
15. Turkey

Cited in *China News Digest* (CND-CN, No. CN99-005). "Internet Technologies in China." CND-CN-L@listserv.cnd.org. June 5, 1999.

56. For example, in spite of technology-induced productivity gains in Chinese manufacturing during the Deng-era, the industrialized countries have also made gains and it appears that the gaps in productivity between China and the OECD countries remains wide. Gu p. 135.

57. One humdred and thirtyone are to be merged into enterprises, 40 are to become technological firms offering research and engineering services, 18 are to function as "intermediate" technological institutions, 24 are to be merged into universities or other research institutes, with the remaining 29 being turned into "large, state-level technological enterprises." China Daily (Hong Kong edition). May 27, 1999. P. 1. Cf. Gu Shulin's account of the reforms of research institutes in the machinery industry in Gu. Part 3. Major reorganizations in the defense industries are likely to force further organizational change in the defense R&D system as well.

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58. "Chinese Researchers Debate Rash of Plagiarism Cases." *Science*. V. 274 (October 18, 1996). pp. 337-8.

59. See, Cao and Suttmeier. "Leadership and Elitism".

60. The notion of "complementary assets" is developed in David Teece. "Capturing Value from Technological Innovation: Integration, Strategic Partnering, and Licensing Decisions." In Bruce R. Guile and H. Brooks (eds.). *Technology and Global Industry*. Washington, DC: National Academy Press, 1987, pp. 65-95.

61. Jane E. Fountain. "Social Capital: A Key Enabler of Innovation." In Lewis M. Branscomb and James Keller (Eds.). *Investing in Innovation*. Cambridge MA. MIT Press, 1998. p. 85.

62. Cited in Fountain. p. 87.

63. Fountain. p. 88.

64. Lewis Branscomb, personal communication.

65. Fountain. p. 88.