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China's Innovation Challenge and the Remaking of the Chinese Academy of Sciences

The remarkable pace of China's economic development since the late-1970s—with annual GDP growth averaging 9.8 percent over the last 28 years—is making China into an economic powerhouse. Measured by nominal GDP, China today is the world's fourth largest economy or, in purchasing power parity terms, the world's second largest (after the United States). However, the rapid economic transformation occurring in China has raised concerns among the country's leadership, and foreign observers, that the growth trajectory—with its overinvestment, resource and labor intensity, and negative environmental and distributive spillovers—has become unsustainable. Hence, the quality of growth has been undergoing a thorough reexamination in the context of national development goals for the next 15 years; the government's goal foresees the establishment of a "well-off society" by the year 2020 in which the per capita GDP will reach US$3000. This goal will require the maintenance of a high rate of growth, but China hopes to find a growth path which avoids the negative features of the recent development experience including, in the words of Premier Wen Jiabao, "an irrational economic structure, the overproduction of low-quality goods, low rates of return, and increasingly severe constraints resulting from energy and other resource scarcity and severe environmental degradation."[1] The keys to sustainable and quality growth, in the

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minds of the Chinese leadership, is to be found in further economic reforms and engagement with the international economy, and the active promotion of scientific development and technological innovation in order to create an "innovation-oriented society" by 2020.[2]

A commitment to make 21st century China an "innovation-oriented society" was made by Chinese President Hu Jintao at an important National Science and Technology Conference in January 2006, an occasion which also saw the unveiling of a new 15 year Medium to Long-term Plan for the Development of Science and Technology (2006-2020). The Plan sets national research priorities, offers a series of supporting policies pertaining to further reforms, intellectual property protection, tax and government procurement measures, and provides substantial resources for meeting R&D objectives—China's ratio of gross expenditures on research and development (GERD) to GDP (GERD/GDP), for instance, is expected to rise to 2.5 percent at the end of the plan period from its 2005 level of 1.30 percent.[3] The Plan emphasizes the importance of "indigenous innovation," of "leapfrogging" to research frontiers in key scientific disciplines, and of utilizing science and technology to support and lead future economic growth. Enhanced capacity for innovation is seen as essential for the creation of a more knowledge-intensive economy needed to ensure China's international competitiveness in the coming years, and is also seen as critical for addressing the increasingly severe problems of population, resources, energy, and the environment as they affect China's social development.

The stress on indigenous innovation should be understood in the context of China's heavy reliance on foreign technology over the past 25 years, a reliance which has created an unwelcome technological dependency in the minds of many in China.[4] This dependency makes China vulnerable to the withholding of advanced technologies by foreign corporations and governments, for commercial and security reasons, and reduces the gains which Chinese producers can realize from participation in international production networks as a result of royalties paid for the use of technologies controlled by others. Hence, a major sub-theme of the 15-year Plan, and the "innovation-oriented society" objective, is the development of Chinese technologies incorporating Chinese standards based upon Chinese owned intellectual property.[5]

It is against this backdrop that we examine the efforts of China's premier academic institution, the Chinese Academy of Sciences (CAS), to remake itself through the implementation of an ambitious program of reform, the "Knowledge Innovation Program." Over the years, CAS has evolved into what is surely a highly distinctive organization, but one whose contribution to national innovative capabilities has been questioned. While comparable to scientific institutions in other countries in some respects (resembling, variously, Germany's Max Planck Society and U.S. national labs and in its honorific functions, the Royal Society and the U.S. National Academy of Sciences), it is truly unique in its size and the range of activities and functions it attempts to accomplish. Few institutions in other parts of the world incorporate in one organizational framework a desire to be:

- a preeminent center of basic research
- a leading institution for cutting-edge high technology R&D
- a performer of research in support of "public goods" programs in defense, agriculture, health, energy, and the environment
- a sponsor of institutions of higher education and graduate training
- a "think tank" of public policy related to science and technology
- a mechanism for high technology entrepreneurship, industrial extension, and economic development in cooperation with local governments
- while also maintaining an identity as an honorific organization whose elite academicians (*yuanshi*) are playing an increasingly important science advisory function.[6]

Yet, in spite of its distinctiveness, its role in helping to create an "innovation oriented society" is now the subject of discussion and redefinition. As the repository of much of the nation's human and material assets for research and development, its role should be clear. But, with its institutional legacy rooted in the centrally planned system of the past, its relevance for a dynamic, globalized, market driven innovation system of the 21st century has been widely questioned by observers both in China and abroad. The role of CAS is thus of central importance for the realization of the objectives of the 15-year Plan. Will it emerge as a leading force in a distinctive Chinese national system of innovation or will it become an expensive and increasingly irrelevant "white elephant?"

SETTING THE CONTEXT

The Chinese Academy of Sciences entered the 1990s with an uncertain future. Its basic institutional architecture was established in the 1950s, under Soviet influence and the legacy of the pre-Communist Academia Sinica, at a time when central planning and public ownership of the economy seemed future certainties. This was also a time when, geopolitically, Marxist-Leninist regimes were in strategic competition with the capitalist democracies, and when China felt itself threatened by the U.S. presence in Asia. With a concentration of outstanding scientists, especially those returnees from oversees, CAS helped develop scientific areas that had not existed in China before, thus laying the foundations for China's modern scientific enterprise during the 1950s. The Academy also came to play an important role in China's strategic weapons programs; its scientists were leaders in weapons design and development, and almost all of the institutions for work on nuclear weapons, missiles, and satellites have been its spin-offs. However, over time, the Academy also became victim to the vagaries of domestic Chinese politics, especially the Cultural Revolution, the political campaign between 1966 and 1976 that traumatized and embittered most Chinese and had a long and devastating influence on Chinese science. As the Cultural Revolution ended, a changing international economic order in which ongoing scientific advance and technological change in the capitalist countries increasingly illustrated the inappropriateness of China's institutional arrangements for research and innovation.

By 1978, CAS faced the tasks of recovering from the damages of the Cultural Revolution and meeting the challenges of its new international environment. And, with the initiation of a series of domestic economic reforms and foreign policy changes in the late 1970s, the Academy's founding assumptions of the 1950s were becoming increasingly irrelevant. National reform policies for science and technology, initiated in 1985, had the effect of drastically reducing guaranteed state funding for CAS (and for government research institutions more generally), thus forcing the Academy and its constituent institutes into a series of commercial ventures.[7] Lenovo, China's leading computer maker which acquired IBM's PC business in late 2004, grew out of the commercial initiatives of the Institute of Computer Technology at this time. By the end of the 1980s, then CAS president, Zhou Guangzhao, was promoting the concept of "one Academy, two systems" (as research institution and commercial technology agent) to give CAS a sense of direction under these new circumstances—as national research center, but one connected closely to the economy.

In place of guaranteed funding for China's research system, the reform policies introduced a series of competitive, project based national programs for research and institutional improvement. These included the National Natural Science Foundation of China, the National High-Tech Research and Development Program (known as the 863 Program), and with help from the World Bank, the National Key Laboratory Program and the National Engineering Research Center Program. Although these provided important resources for efforts to revitalize the Academy during the 1990s,[8] the financial pressures on CAS nevertheless continued, and became especially intense with regard to personnel issues. The Academy was saddled with an aging research force, faced increasing pension costs, and suffered from the "missing generation" problem stemming from the interruption of higher education during the Cultural Revolution and from "brain drain" thereafter. Its discretionary resources for recruiting a new generation of research personnel were thus seriously constrained, especially for attracting back to China the large number of foreign trained students capable of initiating exciting new lines of research.

"INNOVATION" GETS TRACTION

In 1995, the government convened a major National Conference on Science and Technology and, under the slogan, "Revitalize the Country through Science and Education," elevated scientific and technological development to a major national policy priority. Following this conference, new plans and programs were introduced to rejuvenate higher education,[9] expand the role of basic research, advance the ongoing reforms of the science and technology system, and steadily increase R&D expenditures. A major report to the central leadership in 1997, "The Coming of the Knowledge-Based Economy and the Construction of the National Innovation System," by CAS led to the incorporation of the concept of a "national innovation system" in China's evolving science and technology policies. Indeed, the growing interest in national innovation systems marked an important change in Chinese thinking. The concept of innovation came to be understood as more than R&D, and a growing appreciation of its systemic nature prompted the introduction of a broad range of new measures affecting industrial research, intellectual property rights, and venture capital.[10] Chinese science and technology policy was gradually being redefined as "innovation policy."

These policy initiatives to promote a new Chinese national system of innovation represented a novel institutional challenge for CAS to redefine its identity and mission in light of persistent questions about its value to a society that was rapidly abandoning the assumptions which prevailed at the time of its establishment. The appointment of Lu Yongxiang as the new president of CAS in 1997 provided the occasion for the new CAS leadership to convince the top political elite that with a major infusion of financial support, the Academy could transform itself into a center for research and innovation that would serve China's ambitious 21st-century goals for science and technology, *viz.*, to make China a center of original basic research and creative indigenous innovations and, thus, to lessen its dependence on foreign technology.[11] The resulting "Knowledge Innovation Program," introduced in 1998, was seen as a phased "pilot project" of reform which would lead to a remade Academy by 2010. A first "experimental" phase (1998-2000) was to be followed by a five-year implementation of reform measures (2001-2005). CAS is now poised to begin a third phase (2006-2010), in which it hopes to harmonize the Knowledge Innovation Program with the 15-year Plan and "leapfrog" into positions of scientific leadership in key areas of research in support of indigenous innovation and national sustainable development objectives. Its objectives for the third phase include the creation of some 30 internationally recognized research institutes by 2010, with five of these being recognized as world leaders. The Academy's own Medium- to Long-Term Plan, released in March 2006, sets the more ambitious goal of making CAS one of the top three research institutions in the world by 2020. Let us consider the challenges it faces in meeting these goals.

OBJECTIVES AND ACHIEVEMENTS

There is no doubt that CAS today is a markedly different and improved institution than it was in 1998. When KIP began, CAS still supported some 120 institutes, many of which had overlapping missions and research agendas that were inconsistent with the intellectual challenges of 21st-century science. Institutes were seriously overstaffed with non-research personnel, and had more than its share of scientists who had passed their peak productivity and lagged behind international research frontiers. Research programs were often derivative of foreign science, physical facilities were typically run down, and the quality of equipment was very uneven.

During the first two phases of KIP, major progress was made on these problems. The number of institutes was scaled back to 89 (now back up above 90) as a result of hiving off some of the applied research institutes as commercial entities and the reorganization of other institutes to reduce duplication, rationalize missions, and bring focus to new intellectual opportunities and societal challenges.[12]

At individual institutes, traditional disciplinary orientations and missions have been redefined and restructured so as to bring Chinese research into new international knowledge networks of relevance to the IT-bio-nano revolutions. At the Institute of Automation in Shenyang, for instance, a narrow robotic engineering mission has given way to broader multidisciplinary research initiatives in intelligent machinery and advanced manufacturing, while the Institute of Microsystem and Information Technology in Shanghai, formerly the Institute of Metallurgy, has shifted its focus to electronics and information and telecommunications engineering. At the Dalian Institute of Chemical Physics, traditional strengths in physical chemistry, chemical engineering, and catalysis have been reconfigured into an imaginative research strategy of basic and applied research which taps into the various funding streams which now support Chinese science. The Institute of Metal Research in Shenyang merged with the former Institute of Corrosion and Protection of Metals to form an important materials science center incorporating national laboratories in materials science and corrosion studies and engineering research centers for high-performance homogenized alloys and corrosion control of metals. A national drug screening center was set up at the Institute of Materia Medica in Shanghai, with the joint support of CAS, the Ministry of Science and Technology, and the Shanghai municipal government, taking advantage of the strength of the institute in pharmaceutical research and innovation.

Revitalization of the human resource base in the Academy has been approached by programs to recruit a new generation of talented group and laboratory leaders from "brain drain" scientists working abroad, as well as from promising young researchers in China. Among the more prominent of these is the "100 Talents" Program, which offers high salaries, responsible positions, and generous startup research support to leading young Chinese researchers working abroad and in China.[13] Between 1998 and 2004, 899 researchers were recruited using this mechanism, 778 of whom were working overseas (392 of these had doctorates from foreign universities). The Academy also expanded its graduate training, with the total enrollment as of the end of 2004 reaching some 33,000 at its institutes, its Graduate School, and its University of Science and Technology campus. A major new CAS university center in Beijing is now under construction.[14] In 2006, the Academy awarded 4,738 degrees, including 2,478 doctorates.[15] In general, graduate students affiliated with CAS are more likely to participate in important research projects with their advisors than their counterparts at universities.

With these measures, there has been a significant rejuvenation of CAS leadership at the institute, laboratory, and research group levels, and with it, a much stronger linking of the Academy's work to international research frontiers. Whereas the average age of institute directors and deputy directors in 1991 was 56 years, by 2003 it had been reduced to 47. Between 1998 and 2003, CAS made

14,409 new appointments, 67.8 percent of which were senior scientists under the age of 45.[16] While the appointments themselves are significant, reforms in the personnel system affecting the recruitment and retention of young talents are also of long-term significance. New appointments no longer carry promises of lifetime tenure but are subject to careful evaluations early into the investigator's career at the Academy. In addition, salary structures have changed and now recognize the extra responsibilities which come from leadership positions and also include generous provisions for merit increases.

Over the past seven years, and particularly during the most recent second phase, the KIP program has also provided research project support in the three broad domains which CAS takes as its missions—fundamental research, high technology with strategic significance, and science and technology for managing resources and the environment. The pattern of KIP funding, with 70 percent going directly to institutes and 30 percent controlled by CAS headquarters, has given the institutes considerably more discretion in their management of research, and has made them somewhat less dependent on scouring for support from national programs and commercial activities. As a result, research funding at CAS is notably flusher than before KIP, and there has been a notable increase in CAS research outputs. Peer reviewed papers in *Science Citation Index* catalogued journals increased by 148 percent between 1998 and 2004 (from 5,860 to 14,516), making CAS the fourth most productive institution in the world, as measured by SCI publications (after the Russian Academy of Sciences, the University of Texas, and Harvard University). There has been a notable increase in patent applications (3.2 times), patents granted (18.6 times), and registered copyrights over this period.[17]

Implementation of the KIP program has been accompanied by the introduction of a robust evaluation system affecting both institutes and personnel. CAS evaluation work involves administrative reviews to assess consistency of institute activity with CAS policy and KIP objectives, but also involves active peer review of professional work involving leading Chinese and foreign scientists. The evaluation process is thus introducing a useful benchmarking process by which CAS performance can be measured against the best international standards.

Finally, much has been made of the need to introduce a "culture of innovation" as an essential part of KIP. This has taken a variety of forms, from new attention to the ethics of research, to a new commitment to popularization and science-society relations, to a generally more open and cooperative orientation towards relations with universities, industry, and local governments. The strong commercial orientation into which CAS was forced in the 1980s has evolved over time into a more mature approach to the operation of CAS' own companies, and to relations with Chinese enterprises and local governments.[18] As more and more of the Chinese industrial economy is forced into international market competition, the demand for new technologies is increasing and, as a result, CAS-industry relations are on a much different footing than they were 15 years ago. CAS technologies are being "unlocked" by market forces, and commercial ties are being forged with

Key areas (11)	Mega engineering projects (16)*
Energy	Core electronic components, high-end generic chips, and basic software
Water and mineral resources	Extra large scale IC manufacturing and technique
Environment	New generation broadband wireless mobile telecommunication
Agriculture	Advanced numeric controlled machinery and basic manufacturing technology
Manufacturing	Large-scale oil and gas exploration
Transportation	Large advanced nuclear reactor
IT industry and modern services	Water pollution control and treatment
Population and health	Genetically modified organism new variety breeding
Urbanization and urban development	Drug innovation and development
Public securities	AIDS, virus hepatitis, and other major diseases control and treatment
National defense	Large aircrafts
	High definition observation system
	Manned aerospace and moon exploration
Frontier technology areas (8)	**Mega science projects (4)**
Biotechnology	Protein science
Information	Quantum research
New materials	Nanotechnology
Advanced manufacturing	Development and reproductive biology
Advanced energy	
Ocean	
Laser	
Aerospace and aeronautics	

Table 1. Areas and Projects Identified in China's Medium to Long-term Plan

Table 2 Priority Mission Areas for CAS in the Third Phase of the Knowledge Innovation Program (KIP)

- Information technology
- Optical electronics and space science and technology
- Advanced energy technologies
- Materials science, nano-technology, and advanced manufacturing
- Population, health, and medical innovation (involving health care brain research and cognitive science, population, and pharmaceuticals)
- Advanced industrial biotechnology
- Sustainable agriculture
- Ecology and environmental protection
- Natural resources and ocean technologies
- Comprehensive research relying on mega-science facilities

(*) The Medium to Long-term Plan only identifies 13 mega engineering programs.

many of the new high technology companies that have appeared in China in recent years, as seen for instance in the transfer of technology developed in robotic engineering at the Institute of Automation to China's leading computer game developer, the Shanghai-based ShanDa company.

THE CHALLENGES AHEAD

As CAS enters the third phase of the Knowledge Innovation Program, it seeks to respond to emerging national policy priorities expressed in the national 11th Five-Year (2006-2010) Plan and especially the new 15-year Plan. The latter identifies 11 "key areas" of research in support of national needs, 8 areas of "frontier technology" in which China seeks international leadership, and a series of major national projects in science and engineering to support the Plan's objectives (see Table 1).

By proposing a sharper mission focus to its work, CAS hopes to secure a leading role in the implementation of the Plan and its place as the "backbone" of the Chinese national system of innovation. It is thus giving priority to the establishment of a new matrix management scheme in which the activities of its research institutes will be linked to 10 high priority national mission areas, with a new commitment to interdisciplinary basic research in frontier areas supporting the entire effort (so-called "10+1") (see Table 2).

The initiation of this scheme will require the creation of 10 innovation "bases" in the CAS headquarters in order to coordinate mission activities in each area with the work of relevant institutes. It promises to change the nature of the relationships between the institutes and the central CAS in ways which could compromise some of the other objectives of the Knowledge Innovation Program, should mission-oriented objectives from above clash with the pursuit of scientific distinction in selected fields from below.

Thus, while the progress of transforming CAS through the Knowledge Innovation Program has been truly impressive, the problems of implementing phase 3 are not insignificant. They can be summarized as follows:

Human Resources

The availability of human resources and technical talent continues to be a major concern. While CAS has sought to recruit the very best scientific talent, most observers would agree that its success has been mixed: The "100 Talents Program," which offers high salaries, responsible positions, and generous startup research support to leading young Chinese researchers working abroad and in China, has had trouble recruiting top flight talent. Of the researchers the Academy was able to recruit using this mechanism thus far, less than half had received doctorates from foreign universities, far less with permanent and tenured appointments abroad. In general, it has not been possible to attract those Chinese scientists working abroad who are most active at the frontiers of international science, and, indeed, some of these have become more vocal in their criticisms of the Chinese research environment.[19] In addition, China is still losing many of its top students (including those coming out of the CAS educational system) to study and research opportunities abroad, and to alternative employment opportunities in China, including work in universities and in the growing number of R&D facilities operated by multinational corporations. Thus, in spite of many reports about the abundance of scientists and engineers in China, there is intense competition for the best of these, with CAS having to compete on one hand with the high salaries from the industrial sector, and on the other with an improving university environment. CAS' own graduate school system, the world's largest, awarded 4,738 degrees in 2006, including 2,478 doctorates. But, the steady expansion of graduate enrollment in CAS—driven in part by CAS wishing to insure it has a steady supply of young researchers—has made the maintenance of quality control an important issue as the numbers increase.[20]

Thus, in the coming five years, the Academy faces the problem of maintaining an environment that will facilitate the recruitment and retention of top people. High-quality researchers expect a degree of stability in the research environment and worry that the new phase 3 initiatives could threaten that stability. Given the variety of institutes within CAS, due regard must also be given to the development of different types of evaluation standards and processes. The new mission orientation associated with the ten mission areas will clearly make the development of an appropriate evaluation system more challenging. On one hand, CAS aspirations to achieve world-class status in research will put a premium on the design of an evaluation system that will focus on scientific and technical merit. On the other hand, the emphasis on a centrally directed and coordinated mission orientation will call for the establishment of an evaluation system focusing more on the consistency of research performance with national policy and on the extent to which social needs are met. In addition, the evaluation system, especially for new group leaders, generates enormous pressures for productivity among young scientists at a time when they need a few years to get their laboratories established and recruit new graduate students to join their groups. In some cases, pressure for research achievements has caused promising scientists to leave CAS for employment elsewhere.[21]

Programs to improve the talent pool by recruiting Chinese scientists working abroad to return to China also have not escaped some of the problems of fraud and corruption which have plagued Chinese science recently. In some cases, the high salaries and attractive material incentives used in these programs have been abused. Researchers have enjoyed the salaries without taking their research responsibilities seriously, that is, without fulfilling the obligations of appointments, while their employing institutions have been satisfied to use the names and publications by these "star scientists" to improve their evaluations and thus qualify for increased funding. As these programs are related to how China's research money should be most wisely and efficiently spent, the scientific community has petitioned for a crackdown on the returnees who have received the most sought-after grants but failed to devote enough time to research in China.[22] Having noticed the problem, CAS now requires that those recruited into the "100 Talent Program" work full-time in China during their tenure.

Institutional Mission and Focus

Many of the challenges that CAS faces in phase 3 of the Knowledge Innovation Program are tied to CAS' own institutional identity and how it fits into the larger design of the national innovation system. The CAS leadership seeks to integrate and harmonize these diverse functions during phase 3, and to do so in ways which convince China's political leaders of CAS' indispensability. At the same time, CAS continues to face daunting financial challenges in providing social safety nets for both its current employees and its retirees. It believes that it can best perform its functions and meet its responsibilities through more generous state support and through the success of its commercial ventures.

In return for increased government support, though, CAS faces new problems of accountability, with the government wanting assurances that CAS is serving national needs in a cost-effective manner. It is in the face of such expectations that the idea of a stronger mission orientation in phase 3 is being advanced. However, such an orientation runs the risk of imposing excessively top down requirements on the research community in ways which could discourage research creativity and bottom-up innovation, a problem which has been identified by some Chinese scientists working abroad as holding back Chinese science more generally.[23]

A clear definition of the CAS mission is very closely related to active policy debates in today's China over the shape of the national innovation system. As China has moved from a planned to a market economy, there is a growing realization among national policymakers that Chinese industry must become far more innovative if it is to move up the value chain of the international economy. A core question in debates over the future of the Chinese national innovation system is where that innovation is likely to come from. Following the model of the capitalist OECD countries, many in China believe that the development of R&D in Chinese companies is the key strategic task for building a national innovation system. Chinese industrial enterprises, in general, had long been weak in R&D since, under the planned economy, research was centralized in government research institutes. However, in recent years, government policy has tended to favor the development of research in enterprises and statistically, at any rate, more than 60 percent of the nation's R&D is now performed by industry (up from less than 40 percent in the 1990s). This objective of an "enterprise-centered national innovation system" is also an explicit goal of the 15 year Plan, and a series of policy measures have been introduced to further it. This view, however, is not entirely compatible with the CAS-centered view associated with the initiation of the Knowledge Innovation Program.

The role of universities also figures prominently in current debates about the national innovation system. In the planned economy era, universities had a very limited research role in China. However, this has changed dramatically in the reform period as the value of active research in conjunction with advanced training associated with the Western model of the university has taken root, and as new sources of funding for university research, especially the National Natural Science Foundation of China, became available. The scope and quality of university research have grown rapidly, and with them has again come questions as to the role of CAS in relation to universities, especially with regard to the training and subsequent employment of graduate students.

Defenders of the Academy plausibly argue that given the past weaknesses of both industrial and university based research, China has a distinct need for an institution like CAS. Clearly, however, the growth of enterprise research and university research could compromise some of the unique strengths which CAS, in the past, could claim. Thus, in spite of the achievements of the Knowledge Innovation Program to date, there are still voices in China—as there were before the initiation of KIP —questioning whether CAS, in its present form, really has a place in a marketized and globalized China.

In the short to medium term, however, the defenders of CAS are likely to carry the day. Very few Chinese companies, for instance, will be able to put together the combination of scientific and engineering talent, facilities, research management and a strategic vision for innovation of the sort found in leading technology-based companies in the OECD world. Building on its long research tradition, and taking good advantage of the opportunities presented by the Knowledge Innovation Program, CAS does represent a reservoir of assets for research and innovation that are in many fields approaching or exceeding international standards. Similarly, although CAS and China's leading universities are increasingly in competition for professional staff, top graduate students and research project funding, CAS seemingly is able to hold its own by virtue of more generous stipends and working conditions for graduate students and well-equipped laboratories and sophisticated equipment which is not available in universities (in spite of the efforts made to upgrade Chinese universities, only a very few distinguished universities are competitive with the Academy).

In spite of long-standing competitive relations with universities, CAS is also pledged to increase cooperation. Phase 3 plans call for 50 collaborative research projects with universities, the establishment of 20 to 30 joint laboratories, the initiation of joint graduate training programs, and a more active involvement of university professors as consultants and advisers to CAS institutes. China's national nano-technology center is a cooperative effort involving CAS and Beijing and Tsinghua Universities, but the effectiveness of the cooperation remains to be seen.

Although Chinese policy makers are giving much attention to a more enterprise-centered national innovation system—with considerably more expected in the near future[24]—it is unlikely that many Chinese companies will develop R&D capabilities in support of novel, science based technologies in the near future. China's more entrepreneurial high technology companies in the private sector often lack the resources to support their own R&D, while larger state-owned enterprises often find that short-term business objectives are better met by the less risky course of procuring advanced technology from abroad. In some cases, though, we are seeing Chinese companies outsourcing their innovation needs to centers of knowledge creation in China—such as CAS and the universities—or to research centers abroad. CAS-industry and university-industry relations, while still less than ideal, are thus likely to become considerably more important. If so, this suggests that as a matter of national policy, and as an explicit objective of the third phase of the Knowledge Innovation Program, the conditions under which these relations can be enhanced (legally, financially, and in terms of technical infrastructure needed to reduce transaction costs) should get careful attention. Among phase 3 objectives is the establishment of some 100 R&D centers in conjunction with enterprises by 2010 and the development of new technology transfer platforms in science parks and high technology zones.

The debate about the proper role of CAS is also shaped by relations between the Academy and the Ministry of Science and Technology. As in other countries, science policy discourse can become highly political; in this case, reflecting long-standing tensions between CAS and the Ministry. In the early years of the People's Republic, CAS enjoyed a special status as an elite center of research and science policy development. By the middle of the 1950s, however, research facilities were being established under industrial ministries and, to a lesser extent, universities. With such an expansion of the research system, the regime decided on the establishment of a high level planning and coordination body which by 1958 had evolved into the predecessor of the Ministry, the State Science and Technology Commission. These developments led to debates about the role of CAS which are somewhat reminiscent of discussions today. Whereas today's defenders of CAS like to refer to it as the "backbone" of the innovation system, in the 1950s they referred to it as the "locomotive" of Chinese R&D.[25] The Commission, with its different purview remained unconvinced, and over the years, relations between CAS and the Commission were often strained.

In today's China, the Ministry has warily eyed the Knowledge Innovation Program and the generous funding it has received from the government largely independently of the Ministry. Although a State Council-authorized review of the Program by the Ministry was generally positive, questions have been raised about the propriety of the decision making leading to the initiation of Program, which occurred outside of Ministry channels, and involved a direct relationship between the CAS leadership and China's top political elite. But CAS has been able to maintain the strong support of China's political leadership: all members of the Chinese Communist Party Central Committee Politburo Standing Committee visited the Academy between November 2004 and January 2005 to demonstrate approval of the progress of the Knowledge Innovation Program.

CAS, in turn, had been less than generous in their assessment of the Ministry's central role in the preparation of the Medium to Long-term Plan. In particular, voices associated with CAS have been critical of the Plan's mega-science programs, fearing that they would consume a significant portion of China's research budget without having a significant impact on innovative research or the productivity of Chinese science. The widely reported attack by overseas Chinese scientists on the planning process was perceived by the Ministry as representing the views and interests of CAS.[26] It remains to be seen how relations between these two important institutions involved in China's science policy making and implementation develop now that the Plan has apparently gone the way that the Ministry desired.

Defining "Innovation"

Though an oddity in English discourse, the term "knowledge innovation" has, as we have seen, captured the imagination of Chinese political and scientific leadership. In the context of science and technology policy, the term "innovation" usually refers to the incorporation of novel ideas into new processes or products which are actually commercialized or brought into practical use, and from this definition has come a vast field of empirical research and much theorizing which takes as its point of departure the fact that "innovation," in the sense, is both more than R&D and different from "discovery" or "invention."

As used in the Knowledge Innovation Program, though, the concept is far more diffuse and inclusive to the point, perhaps, of being ill defined. While it seems to include notions of technological innovation, as recognized in English, it also includes the idea of major institutional reform and revitalization (institutional innovation) in support of creativity in scientific discovery. In addition, it is also intended to convey a sense of attitudinal change—an openness to new ideas and new institutional relationships and, with patriotic overtones, the importance of "revitalizing the nation through science."

While the concept of "knowledge innovation" has had considerable appeal in the context of contemporary Chinese politics and public policy, its very diffuseness poses certain problems for the realization of phase 3 objectives, since the various different meanings of "innovation" found within the Knowledge Innovation Program, imply different organizational arrangements and managerial strategies; research management in support of scientific discovery, for instance, may not be the same as the management of innovation in support of the introduction of new technologies into commercial use. Definitional problems of this sort of closely tied up with the interconnectedness of the challenges facing the implementation of the Knowledge Innovation Program in phase 3.

One of the major human resource challenges, for instance, is to find outstanding individuals who can serve as the leaders of CAS institutes. However, the qualities one might wish to have in such individuals might vary according to the understanding of innovation which is operative, which in turn is very closely related to the clarity with which CAS missions are defined. These, in turn, cannot be understood independent of the broader national system of innovation.

To secure a central role of CAS in the national innovation system, it will be necessary for the Academy during phase 3 to think in new ways about the relationships between its institutional structure and the numerous and diverse functions it currently attempts to perform. This is clearly what the establishment of the "10+1" formula is intended to accomplish. But, whether it can succeed in this endeavor, remains to be seen in light of the potential conflicts in performance standards and lines of accountability associated with the Academy's many functions and objectives.

For many of CAS' research staff, the achievement of the kinds of scientific distinction associated with some of the phase 3 objectives is best approached through an investigator driven research portfolio. This approach would accord with the Academy's basic research traditions and interests in becoming a world-class graduate training facility. On the other hand, the desire to link the Academy's activities to the achievement of high priority national objectives calls for a rather different management model, one stressing more top-down direction and less investigator autonomy.

The work of attempting to serve national needs, in turn, can be thought of as having two somewhat different managerial challenges. On one hand, national needs can be met through service to commercial entities engaged in market competition. Although CAS, historically, has been weak in service to market oriented enterprises, the commercial pressures it has faced over the past 20 years have produced considerable technology transfer experience and engendered a variety of transfer mechanisms. These include contract research, the licensing of proprietary technologies and the spinning off of companies from CAS institutes. An especially interesting approach has been the involvement of CAS units in special high technology zones established by local governments. In the case of the Institute of Computer Technology, these include integrated circuit design centers in Suzhou and Ningbo, a mobile computing center in Shanghai, a software development center in Zhaoqing, and a center for intelligent electronic technology in Taizhou. But, in spite of improved relations with industry, many problems remain, and there are often mismatches between the relatively advanced technologies being developed by CAS and the willingness and ability of Chinese companies to adapt them. In some ways, the work of CAS fits more naturally with the technology interests of multinational corporations and it is not surprising, therefore, that we are seeing new commercial relations developing through research outsourcing from corporations to CAS institutes.

A number of other national needs involve the supply of public goods which cannot be readily met through market transactions. For CAS to serve these needs requires that effective linkages be developed with other state bureaucratic systems (for instance, those dealing with public health, agriculture, defense, weather forecasting, and environmental protection), and different technology transfer platforms from those used in support of commercial transfers. CAS is not without experience in supporting the provision of public goods (its contributions to national defense technologies and to natural resource surveys, for instance, come readily to mind), but to do so effectively requires considerable familiarity with the procedures and expectations of different administrative agencies (which typically have their own network of research institutes) and the stakeholders associated with them. The growing relationships with local governments may be quite useful for these purposes in some cases. The Zhaoqing software development center of the Institute of Computing Technology, for instance, is a venture which also involves China's Ministry of Science and Technology and the government of Brazil. It has as major objectives the development of low-cost information technology and the delivery of IT services to Chinese farmers. As part of the program to build an "innovation oriented society" and implement the 15 year plan, a number of Chinese regions have developed "regional action plans" which CAS has pledged to support. But CAS-local government relations are no substitute for the deployment of substantial managerial resources and interagency coordination at the national level in support of national needs, and too much involvement with local governments is seen by some CAS scientists as diverting attention away from other missions which are regarded as more central to the Academy as a *national* leader in science and technology.

A special word should be said about the relationships between the innovation aspirations of CAS and its contributions to national defense. It is thought that defense-related work in CAS constitutes an important share of its budget which, if anything, is growing. As noted above, service to national defense has been an important part of the CAS mission since the 1950s, but in the past, it had been Chinese practice to wall off research on defense technologies from civilian work. In the reform era, however, this has changed and there is increasing attention to civilian-defense integration in technological development, a view reaffirmed in the 15-year Plan. This poses a number of interesting questions about defense-related work at CAS. Can generous funding of defense-related work be a spur to technological development for civilian purposes, or will the civilian applicability of defense research continue to be attenuated, as in the past? Will important high technology work on the civilian side find utility on the defense side? Will strong support from the defense establishment become a new "iron rice bowl" and discourage the entrepreneurial risk taking necessary for innovation? The scarcity of information on these matters in no way diminishes their importance for understanding CAS' innovative potentials.

CONCLUSION

The CAS agenda for the third phase of the Knowledge Innovation Program is very ambitious and, by its very nature, is one that puts a premium on institutional design and managerial capabilities. However, the multiple functions that CAS assumes can threaten the maintenance of clear organizational focus. Under such circumstances, a case might be made for greater specialization and functional differentiation in organization instead of efforts to achieve a higher level of integration of functions through the matrix organizational strategy noted above. While China certainly has a variety of national needs to which CAS can respond, there is a danger that the overly managerial approach being proposed will dilute a number of CAS strengths and compromise other goals and accomplishments of the Knowledge Innovation Program.

CAS thus faces a series of classical innovation-related questions in its quest to become the "backbone" of the innovation system. Do its phase 3 strategies actually encourage or discourage the development of a culture of creativity where risk-taking, self initiative, and new ideas and approaches are supported and rewarded? Can it develop a cadre of professional R&D managers with the appropriate skills and training for managing interdisciplinary teams in an increasingly internationalized research environment? How does CAS "segment" its "market," and "customers," set priorities for its various stakeholders, and specialize its organizational arrangements to accord with this segmentation? Should it be defining its mission principally in terms of the supply of public goods or private goods, and does it define "success" in terms of emulation, imitation, incremental innovation, or radical innovation? And, how does it define a reasonable educational mission which both meets its own research and human resource needs and complements the activities of Chinese universities? In its commitments to serve national needs, can it also be a credible partner in international collaboration?

Even with such an array of strategic problems, CAS has already made significant progress in remaking itself into an internationally distinctive organization, remarkable for its aspirations and achievements in a broad range of activities from basic research and graduate education to high technology development and industrial extension. The growth of research in Chinese enterprises, and the continuing strengthening of university based research as China implements its Medium and Long-Term Science and Technology Development Plan over the next 15 years will undoubtedly represent challenges to CAS' identity and mission. Nevertheless, CAS will continue to play a central role in the country's development of science and technology and its emergence as a major player in international research and innovation seems assured. For all its challenges, the Academy is becoming a place which will increasingly attract the attention of the international technical community, especially as it (institutionally) and its scientists become further embedded in a wide variety of the world's dynamic global knowledge networks. If we are witnessing the gradual emergence of a new Chinese science and technology superpower, as seems likely, it will be one that, by virtue of its size and complexity, can accommodate a variety of institutional models. Given current trends with respect to global innovation, this will necessarily involve and require enhancing its capabilities to engage in cross-border, multi-national collaborative research. In spite of the well-known problems with central research academies in the 20th century, however, the Chinese innovation system of the 21st century is likely to ensure the social relevance, as well as the scientific distinction and influence, of this extensively reformed and increasingly capable institution.

We invite reader comments. Email <editors@innovationsjournal.net>.

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1. Wen Jiabao, "Speech at the National Science and Technology Conference (Beijing, January 9, 2006)." *Xinhua Domestic Service*. January 16, 2006. In World News Connection, January 16, 2006.
2. *Ibid*.
3. Purchasing power parity terms of GERD put China third in the world after the U.S. and Japan. However, GERD/GDP comparisons must be used with care since China recently revised upward its 2004 GDP by 16.8 percent.
4. The Plan calls for the reduction of this dependency in quantitative terms, with reliance on foreign technology to be reduced from 50 percent to less than 30 percent by 2020.
5. For an expanded discussion, see Richard P. Suttmeier, Xiangkui Yao, and Alex Zixiang Tan, *Standards of Power? Technology, Institutions, and Politics in the Development of China's National Standards Strategy* (Seattle, WA: National Bureau of Asian Research. 2006).
6. In spite of this expansion of the policy advisory role, abuses in electing and rewarding academicians are getting more public attention, and have made the academician system increasingly controversial. See Cong Cao, *China's Scientific Elite* (London and New York: RoutledgeCurzon, 2004), espe-

cially Chapter 9.

7. The reduction in state funding, part of a package of reforms promoted by the State Science and Technology Commission, the predecessor of the Ministry of Science and Technology, was driven by a desire to force government research institutes to become more attentive to market forces and to the needs of users of the knowledge being generated. While the budget-reducing approach to reform has had important consequences for the institutions of China's research system, not all of these are seen in a positive light by members of the technical community, including officials of CAS. In this view, China was not prepared for the reforms (resulting in much wasted effort), which left Chinese R&D seriously under-funded for more than a decade, and promoted an unhealthy dependency on foreign technology in the Chinese economy.

8. As noted further, below, the programs to establish national key laboratories and engineering research centers have helped produce national centers of excellence in a number of institutes which have been important building blocks for the implementation of the Knowledge Innovation Program.

9. For instance, the Ministry of Education introduced its "211 Program," to position some 100 Chinese universities as world-class distinguished academic institutions in the 21st century. Later, the Ministry of Education reaffirmed the goal through the "985 Program," so named to commemorate the speech by then Chinese President Jiang Zemin on the occasion of the 100 anniversaries of Beijing University in May 1998.

10. The concept of "national innovation system" was actively promoted in a major review of China's science and technology reforms performed by Canada's International Development Research Centre (IDRC) for the State Science and Technology Commission, the predecessor of the Ministry of Science and Technology. See, IDRC. *A Decade of Reform: Science and Technology Policy in China* (Ottawa, Canada: IDRC, 1997), especially Chapter 5.

11. The Knowledge Innovation Program proposal was first presented as part of "The Coming of the Knowledge-Based Economy..." report. The report was submitted to the then Chinese President Jiang Zemin through his son Jiang Mianhong, then director of CAS Institute of Metallurgy in Shanghai, who was appointed vice president of the Academy in November 1999. The endorsement by Jiang Zemin was instrumental in the initiation of the Program.

12. For earlier accounts of KIP reforms, see Hui Li, "Chinese Academy of Sciences: Reform Shatters 'Iron Rice Bowl," *Science*, Vol. 279 (January 30, 1998, p. 649; Hui Li, "Chinese Academy of Sciences: Institutes Reinvent Themselves as Part of Well-Funded Reform," *Science*, Vol. 283 (January 8, 1999), pp. 150-53; Jeffrey Mervis, "Chinese Academy of Sciences: Neuroscience Institute Breaks New Ground," *Science*, Vol. 283 (January 8, 1999), pp. 150-51; "Chinese Academy of Sciences: CAS President Engineers Major Reform of Institutes," *Science*, Vol. 286 (November 26, 1999), pp. 1671-73; Ding Yimin, "Chinese Academy of Sciences: In China, Publish or Perish Is Becoming the New Reality," *Science*, Vol. 291 (February 21, 2001), pp. 1477-79.

13. Recruits into the "100 Talents Program" are eligible to receive RMB2 million (US$250,000) in start-up funds.

14. New graduate students do their basic coursework in Graduate School and then move to CAS institutes for their research and thesis preparations.

15. <http://www.cas.cn/html/Dir/2006/08/15/2825.html> (accessed on August 16, 2006).

16. Chen Zhu, "Historical Missions of Young Science Administrators: Rational Thinking on the Younger Leadership of China's Research Institutions" (in Chinese), *Nature*, Vol. 432, China Voices II (18 November 2004), pp. A24-A29.

17. In spite of the impressive quantitative gains represented by these productivity measures, the qualitative performance has lagged. Thus, in spite of the 4th rank in number of papers catalogued by *Science Citation Index*, their impacts were disappointing. CAS papers ranked 83rd in the world in terms of the total number of citations to them and ranked 3,170 (out of 3,292) in citations per publication. We are grateful to Jin Bihui of CAS for providing these figures.

Between 2000 and 2004, China ranked 14th in total number of *Science Citation Index* papers, 8th in total citations and 123rd in citations per paper, while one of the goals of the 15-year Plan is to have China in 2020 be among top 5 in terms of total citations.

18. CAS has 10 major companies under it, including Lenovo, and less well-known but nevertheless large Di'ao Pharmaceutical Group based in Sichuan province. In addition, many institutes have spun off successful companies. The San Huan Corp., for instance, is a spinoff from the Institute of Physics, which employs the knowledge generated by research into rare earth metals to produce high-quality magnetic materials. Overall, they are now some 490 institute spinoffs. In all, CAS enterprises employed approximately 60,000 people in 2003 and had an income of RMB53.4 billion (US$6.4 billion).
19. See, for example, David Cyranoski, "Biologists Lobby China's Government for Funding Reform," *Nature*, Vol. 430 (26 July 2004), p. 495; Yi Rao, Bai Lu, and Chen-Lu Tsou, "A Fundamental Transition from Rule-by-Man to Rule-by-Merit: What Will Be the Legacy of the Mid-to-Long Term Plan of Science and Technology?" (in Chinese), *Nature*, Vol. 432, China Voices II (18 November 2004), pp. A12-A17; Mu-ming Poo, "Big Science, Small Science" (in Chinese), *Nature*, Vol. 432, China Voice II (18 November 2004), A18-A23.
20. This concern for ensuring a supply of young, new personnel reflects the persistence of a pre-reform planner mentality, its preoccupation with shortages, and the need for vertical integration to manage shortages. By extension, it also points to continuing imperfections in the market for highly skilled labor.
21. In one case, in September 2005, CAS physicist Mao Guangjun committed suicide for reasons including the pressure after his failure in performance evaluation. See Ding Yimin, "Scientists' Suicides Prompt Soul-Searching in China," *Science*, Vol. 311 (17 February 2006), pp. 940-1.
22. See, for example, David Cyranoski, "Petition Calls for Clampdown on Absentee Chinese Researchers," *Nature*, Vol. 421 (2 January 2003), p. 3; and Hepeng Jia, "China's reverse brain drain plan 'risks backfiring,'" *SciDevNet*
<http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=2322&language=1> (accessed September 5, 2005).
23. See footnote 19.
24. As noted above, accompanying the issuance of the Medium and Long-Term Plan for the Development of Science and Technology, China introduced a variety of policies favorable to Chinese companies to strengthen their research and innovation in the national innovation system. But it remains to be seen whether these policies will be perceived in the international community as WTO compliant.
25. Richard P. Suttmeier, *Science and Revolution: Science Policy and Societal Change in China* (Lexington, MA: D. C. Heath and Company, 1974).
26 Hao Xin and Gong Yidong, "China Bets Big on Big Science," Science, Vol. 311 (March 17, 2006), pp. 1548-9. See also footnote 19.