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China Aims High in Science and Technology
An Overview of the Challenges Ahead

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1.1 Introduction

China's science and technology prowess is expanding. Whether one examines the number of science and engineering papers that Chinese researchers publish in international journals, the amount of investment made in research and development (R&D) in China, or the number of patents that Chinese are filing, statistics indicate that the science and technology (S&T) capabilities of the People's Republic of China (PRC) are developing rapidly (see Figure 1.1). These advancements are in line with China's leaders' clearly stated goal to make China "an innovation-oriented country" by 2020 and a "world's leading science power" by 2050.[1]

The motives behind China's pursuit of techno-superpower status are manifold. First and foremost, China's political leadership views raising the S&T capabilities of Chinese companies as imperative for economic development to continue. A "shift in the country's economic mode"[2] and significant technological progress are necessary for China to meet the target of quadrupling its 2000 gross domestic product by 2020.[3] As the world economy becomes more knowledge-driven, so will the importance of having the capacity to acquire knowledge as well as to disseminate and apply knowledge. Though China has partially succeeded in moving from labor-intensive, low technology production to high technology manufacturing, it has done so by heavily relying on imported technology. Means of production

Figure 1.1 Selected S&T indicators of China.

	1997	2001	2005
GERD (USD billion)	6.1	12.5	30.1
GERD/GDP (%)	0.64	0.95	1.34
Government S&T appropriation (USD billion)	4.9	8.4	16.4
Government S&T appropriation/total government expenditure (%)	4.4	3.7	3.9
Scientists and engineers (1000 FTEs)	588.7	742.7	1119
Number of patent applications (in China)	114.208	203.573	476.264
S&T papers catalogued by SCI, ISTP, and EI	35.311	64.526	153.374
Exports of high-tech products (USD billion)	16.3	46.5	218.3
Percentage of high-tech products in total exports	8.9	17.5	28.6

Notes: GERD = General Expenditure on R&D, SCI = Science Citation Index, ISTP = Index to Scientific and Technical Proceedings, EI = Engineering Information, FTE = Full Time Employment.

The only exception in the otherwise steady growth in all sectors is the immense growth in exports of high-tech products. The reason for this is at least partially the heavy involvement of foreign and Taiwanese companies in China's high-tech exports.

Source: MOST, China Science and Technology Statistics Databook, http://www.sts.org.cn/sjkl/kjtjdt/index.htm.

for high technology products are to a large extent dependent on the transfer of foreign technology to China. In 2005, 88 percent of China's high-tech exports were produced by foreign (or Taiwanese) owned firms.[4]

So, globally, China is still a borrower, not a creator of new technology. To prosper in an age of knowledge-based economy, a country needs to build a national innovation system within which new knowledge can be transformed into economic growth and welfare.[5] To quote Hu Jintao, China's President and Chinese Communist Party General Secretary: "Real core technologies cannot be purchased but can only be achieved by innovation."[6]

Intertwined with the economic imperatives to upgrade China's S&T capabilities are China's political and military ambitions. These are directly linked to the comprehensive nature of China's aspirations to attain international respect as a major power. While Japan's ascent to economic power in the 1960s and 1970s was distinguished by a low political and military profile, China's emergence as a great trading power has taken place hand in hand with its strengthening political and military might.[i] Science and technology are needed not only to maintain economic growth, but also to boost the nation's international prestige (e.g., by sending a man into space) and modernize the People's Liberation Army. Nationalism is an important component when assessing policies intended to legitimize the Chinese Communist Party's right to govern; hence, advances in science and technology also need to be viewed as a means to enhance national pride. According to Hu Jintao, "Science and technology, especially strategic high technology, is increasingly becoming . . . the focus of competition in comprehensive national strength."[7]

In sum, China aims high in science and technology. China's leaders have made "indigenous innovation" a cornerstone of the country's future development. Several indicators, to be discussed later, show that China has already made impressive strides in S&T in a mere two decades. On the other hand, China's research environment has been criticized as detrimental to individual creativity, corrupt and too politicized;[ii] the quality of Chinese research papers has been deemed low; and S&T policy-makers have been described as overbearing.[8] As always, contradictions abound when analyzing China and where it is heading. How realistic is the ambition to make China an innovative nation by 2020? The chapter addresses this question, providing an overview of the major factors that impact China's pursuit of innovative high technology research.

As is fitting for any assessment of developments in China today, for every argument that indicates that China can achieve its goal, there is a counterargument that says that China will take much longer to

[i] Obviously there are noteworthy differences between China and Japan, which contribute to the comprehensive nature of China's rise: China is home to over a fifth of mankind; China has nuclear capability and in terms of manpower the world's largest armed forces; China is a permanent member of the United Nations Security Council.

[ii] Off-the-record research interviews, upon which this chapter in part draws, were conducted by the author with 103 researchers, officials, and entrepreneurs working in China in the field of S&T in Beijing, Hangzhou, Helsinki, Hong Kong, Shanghai, San Francisco, and Washington DC, 1 November 2005–15 January 2007.

be regarded as an innovative society. China is experiencing complex transition processes that are taking place simultaneously, making any attempt to form a general picture, at best, difficult.

1.2 Looking to the future: National objectives

In February 2006, the Chinese government articulated its S&T goals and strategy for the next 15 years.[9] Dissecting the mammoth "Medium- and Long-term S&T Development Plan" is a mind-boggling task. Wading through 68 prioritized subjects in 11 key fields, 16 mega engineering projects, eight S&T frontiers for research, four major research projects, and eight measures to guarantee the building of an innovative China certainly drives home the message that a wide variety of competing interests and opinions were considered in the plan's drafting process (see Figure 1.2). Some 2000 opinions were initially solicited.

The tangible goals of the 15-year S&T plan can be summarized as follows: China must increase its "indigenous innovation" capacity in order to reduce its reliance on foreign technology to 30 percent or below (from its present reliance of 60 percent);[10] China should be among the top five countries in the world in terms of the number of patents filed for "indigenous" inventions and the frequency of citations in international science papers;[11] China should build several world-class research institutions and universities.

Figure 1.2 Key areas and frontier technology focuses of China's "Medium- and Long-term S&T Development Plan."

Key areas (11)	Frontier technology (8)
Energy	Biotechnology
Water and mineral resources	Information
Environment	New materials
Agriculture	Advanced manufacturing
Manufacturing	Advanced energy
Transportation	Ocean
IT industry and modern services	Laser
Population and health	Aerospace and aeronautics
Urbanization and urban development	
National defense	
Public securities	

What the government views as critical in resolving the country's bottlenecks is perhaps best reflected in the development goals: China should master core technologies in the equipment manufacturing and information industries; catch up with the advanced nations in agriculture-related S&T capabilities; develop energy, energy conservation, and environmental technology; improve the prevention of major diseases; develop modern weaponry; as well as achieve international levels in cutting-edge technologies in information, biology, materials, and aerospace.[12] The need for "indigenous innovation" (*zizhu chuangxin*[iii]) and "leapfrogging" as well as more efficient utilization of China's resources are underlying themes in the plan.

As to the strategy to attain these goals, the government decreed that enterprises must be the driving force behind innovation, and both intellectual property rights (IPR) and standards should be developed as tools to strengthen the competitiveness of Chinese companies. Companies that invest in R&D can expect to receive tax incentives and low-interest bank loans as well as the right to depreciate fixed assets such as facilities.[13] The government has already promised preferential policies to 103 enterprises that it has deemed "innovative."[14] In addition, according to the 15-year S&T plan, government agencies in accordance with government procurement regulations should be obligated to purchase products of "indigenous innovation" that have been developed by domestic enterprises.[15] It is not clear, however, whether these proposed regulations will result in trade-related friction.[16]

According to the Chinese government's plans, expenditure in R&D is to increase substantially. By 2010, investment in R&D will account for 2 percent of GDP, compared to 1.34 percent in 2005. By 2020, the figure should be 2.5 percent of GDP. If reached, this investment level would put China on par with several countries of the Organization for Economic Cooperation and Development (OECD). China would also surpass the European Union in level of R&D investment intensity[17] (see Figure 1.3 and Figure 1.4).

[iii] According to co-author Chunli Bai, *zizhu chuangxin* reflects a goal with a threefold dimension: (1) genuinely original innovation, (2) integration of existing technology, a process, described by Bai, as "one in which many technological innovations are integrated, culminating in the production of a new product," (3) re-innovation, in other words assimilation and improvement of imported technology (discussion with Bai, Beijing, 17 October 2006).

Figure 1.3 R&D expenditure in selected countries.

	Finland 2005	Japan 2004	USA 2004	EU-25 2005	UK 2004	China 2005	India 2003–04
Expenditure on R&D as a % of GDP	3.48	3.18	2.68	1.85	1.73	1.34	0,78 (e)

Note: (e) estimate.

Chinese GERD experienced a rapid annual average growth rate of 19.7% in 2001–2005. This can be partially explained by its low starting point, but the difference between the speed of China's growth and that of, for example, United States (1.7%), EU-25 (1.5%) or Japan (2%) during the same time frame is still enormous.

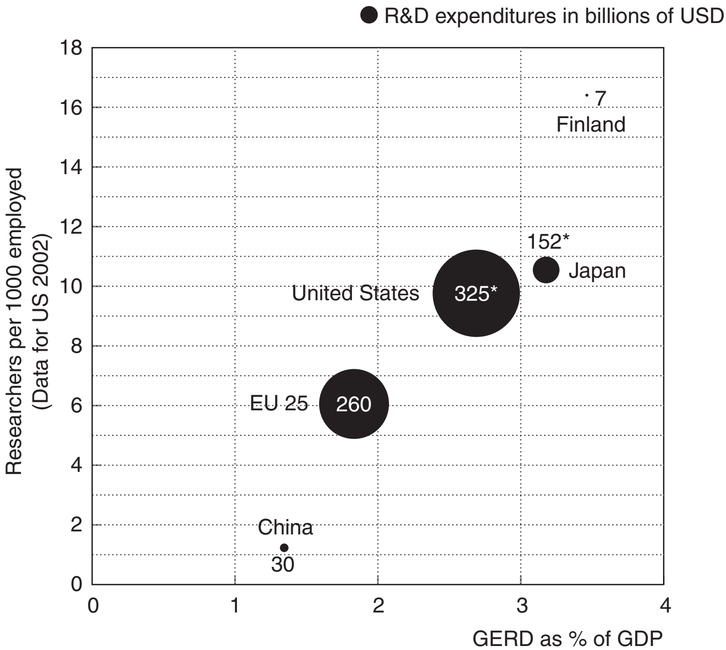
Source: Eurostat 6/2007; Research and Development Statistics, Government of India: http://www.nstmis-dst.org/RnDPDF/Table%20-%202.pdf.

1.3 Legacies of the past

When Chinese Communist Party leaders in late 1978 approved major reforms focusing on the "four modernizations" (agriculture, industry, science and technology, and defense), China's research and development structure was centrally planned, hierarchal and bureaucratic. It had been developed from the Soviet model.[18] Science and technology resources were, to a great extent, dominated by the military, which led to China developing atomic and hydrogen bombs and ballistic missiles. There was hardly any interaction between institutions, a legacy of the past that still plagues the Chinese R&D system.

The reform period ushered in an era of substantial restructuring of the R&D system. Over the past 25 years, hundreds of research institutes and governmental entities have been merged, abolished, or converted into commercial entities. Indeed, the "past" refers to two phases, pre-1978 and post-1978 to the present, that is the nearly three decades since Deng Xiaoping opened China's doors to Western science and technology. The Chinese government's S&T roadmap for the coming years is entrenched in the S&T reforms of these past decades—"a complex story of 20 years of policy development and institutional reform."[19] During that period the commercialization and internationalization of science took place, not only in China where society at large was undergoing major transformation, but also globally.[20] The emphasis placed on technological self-reliance during the latter part of the Mao era was replaced—others would argue complemented—by an overwhelming reliance on foreign technology.[21] Despite shortcomings,

Figure 1.4 Research and development indicators in selected countries, 2005.



Note: * 2004 data.

Chart shows relative ranking in number of researchers per thousand employed (vertical axis) against gross expenditure on R&D (GERD) as a percentage of GDP (horizontal axis). Absolute expenditure on R&D is also shown (in billions of USD). So, China has relatively few researchers in proportion to the total employed population, while Finland (a country of 5 million inhabitants) has a very high percentage of researchers although China's absolute expenditure on R&D is nearly five times that of Finland. There is an ongoing debate regarding whether one should use real terms or purchase power parity (PPP) when assessing figures related to the Chinese currency. In PPP terms, the figures for China would be significantly higher than in real terms. For simplicity and consistency, all the figures in this book are in real terms.

Source: OECD MSTI 2006-2; Eurostat 6/2007. Figure adapted from OECD Science, Technology, and Industry (STI) Scoreboard 2005.

the S&T reforms of the past two decades have led to the substantial upgrading of China's S&T capabilities, especially in areas such as telecommunications, bio- and nanotechnology.

The legacy of the pre-1978 past includes, on the one hand, the loss of a generation of scholars due to the breakdown of the education system during the Cultural Revolution (1966–76), and, on the other hand, Confucian reverence for education and scholarship, which has propelled Chinese parents to sacrifice for their children's education and spurred Chinese youth into academia. Natural sciences have been and still are held in esteem over social sciences. Moreover, due to the political upheavals of the first 40 years of the PRC, parents have encouraged their offspring to pursue science and engineering (S&E) majors in the hope that scientists and engineers would run a smaller risk than writers or social scientists of being targeted during political campaigns.[iv] Most members of China's ruling Politburo are engineers.

There are other legacies of the past that are relevant to this chapter's focus on the factors that effect China's pursuit of innovative high technology. Besides weak cross-institutional communication, Chinese researchers bemoan the strongly bureaucratic nature of the current S&T system. Though a peer review system for allocating grants has been in place for 20 years, many are critical of the large portion of research funding going to prominent scientists who have good connections with the bureaucracy (privilege based on personal relationships is endemic in Chinese society). They disapprove of basic research being neglected, and point out that even when basic research receives funding, the bureaucrats decree in which prioritized fields basic research should be pursued.

The notion of serving the nation is without doubt one legacy of the past that affects the direction of S&T today. Science and technology officials want to ensure that research is conducted, not for the sake of research but in fields that will benefit the nation. People are no longer expected to do good merely for the sake of the country (or for ideological reasons), as in the past, but are enticed with above average salaries, spacious housing, and overseas travel. Scientists and engineers are now part of the elite, contrary to the Mao era. In research interviews conducted with Chinese scientists, every interviewee said that while he or she, as a Chinese, could accept on a personal level the demand that scientific work should help solve the nation's pressing problems, as a scientist he or she resisted the notion of outside

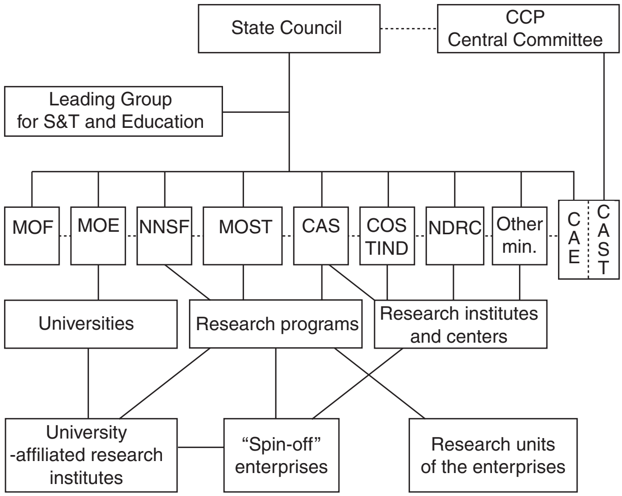
[iv] Today, university departments teaching economics, finance, and business management compete with engineering and science departments for the brightest students.

interference. Many experienced researchers questioned the practical feasibility of serving the public good while simultaneously fulfilling the government's desire for "indigenous innovation." These tasks require entirely different approaches. The former does not necessarily require cutting-edge research, rather adaptation of technology to local needs and conditions.

The government's call for "indigenous innovation" is also, in some respects, a legacy of the past—yet another catchphrase with a subtle political message. According to a senior academic involved in the final stages of formulating the 15-year S&T plan, focusing on "indigenous innovation" was "a way to highlight the government's disappointment" over China's poor record of domestic technological innovation and overwhelming reliance on foreign technology.[22] As early as 1995, when the government vowed (yet again) to strengthen the nation through science, technology, and education, China's president said, "If we do not have our own autonomous ability to create innovation and just depend on technology imports from abroad, we will always be a backward country. . . . we must remain focused on raising China's ability to do research and development on its own."[23] This aspiration has not materialized. As stated in January 2006 by the *Renmin Ribao* [People's Daily] the mouthpiece of the Chinese Communist Party, "the technological level of China's industries and their capabilities to independently innovate is low."[24]

China's S&T leaders have been adamant in reassuring foreigners that the emphasis on "indigenous innovation" does not mean that China intends to reduce international research cooperation. This seemingly contradictory stance fits in well with the dualistic nature of S&T policy-making (this applies to several fields in China besides S&T, in part due to the transitional nature of the economy and society at large). On the one hand, the government appears stuck in the rut of central planning methodology, and continues to churn out grandiose plans, as it did in the Mao Zedong era. The bulk of central government R&D funding is channeled through five gigantic research programs (Key Technologies, Spark, 863, Torch, and 973) and numerous mega-projects, most of them administered by the Ministry of Science and Technology (MOST), Chinese Academy of Sciences (CAS), or National Natural Science Foundation (NNSF) (see Figure 1.5).[25] On the other hand, the government allows market forces to play a larger role in deciding the fate of state-owned

Figure 1.5 Entities influencing policy-making in field of high-tech research.



Besides ministries, a whole host of entities affect policy-making, either formally or informally, in the field of high-tech research. For example, CAST (China Association of Science and Technology) is an umbrella organization of S&T academic and industry societies directly under the Central Committee of the Chinese Communist Party (CCP) and though it does not have formal decision-making powers, it is influential (the present Secretary-General is Deng Nan, the late Deng Xiaoping's daughter). Research institutes affiliated with ministries, CAS, universities, or enterprises can also affect policies at the provincial level. There are five major national research programs: The Key Technologies R&D Program was started in 1982 to develop technology urgently needed for industrial upgrading. The Spark program's goal is to introduce advanced technologies to rural areas. "863" (launched in March 1986) is the "High tech research and development programme" that aims to develop advanced technologies such as IT, biotechnology, and new materials. The Torch program's emphasis is on developing new technology industries. The "National basic R&D program," is "973" started in June 1997. It followed and absorbed the "Climbing program" (initiated in 1989), both of which were intended to make up for the neglect on basic research during the reform era. In February 2007, the Chinese government announced a new funding program for research on key technologies.

enterprises (SOE) and has opened the door to private education. Other contradictory approaches are evident. Chinese S&T officials say that they realize that innovation cannot be dictated from above, while in reality, by stipulating specified research fields and numerically explicit goals, they are attempting to do precisely that. Moreover, when questioned about the feasibility of the ambitious targets set by policy planners, S&T officials tend to answer that plans are just that—plans, and are made to be adjusted.[26] Technology development during the reform period has been characterized as "one of restless change."[27] This resilience, this readiness to adapt to new conditions, and to try alternative paths has to also be seen as a strength of the present Chinese system.

1.4 Creation and diffusion of knowledge

China's S&T landscape is complex, as is befitting a nation as large and diverse as China. The vast majority of high-tech research is concentrated in Beijing and Shanghai. China is living proof of Richard Florida's argument that "the world is spiky."[v] In terms of economic strength and cutting-edge innovation, only the regions around Beijing, Shanghai and Guangzhou are truly consequential. Moreover, innovation strategies in the Pearl River Delta area, encompassing Guangzhou, Shenzhen, Hong Kong, and several cities of over one million inhabitants, focus research on exploring novel applications, rather than basic research.[28]

Though China's S&T landscape is geographically easy to sketch, the picture that emerges of the main actors resembles a complex montage. In addition to the researchers, decision-makers, and educators, important components include foreign direct investment, multinational corporations (MNC), and China-based foreign researchers, most of whom are of Chinese heritage, with academic degrees from foreign universities and work experience abroad, especially from the United States.

1.4.1 The main institutional actors

Knowledge is created and diffused in China by an individual or a group in schools and universities, as well as in research institutes, research departments or research centers. A research unit, regardless of size, is administered by an enterprise (state-enterprise or nonstate enterprise, in other words nongovernmental, private, stockholding, cooperative, joint-venture, or foreign-owned), a university or college, a governmental organization at either the central or local level

[v] Florida argues that contrary to Thomas Friedman's notion that the world is flat, the world of innovation consists of growing peaks and sinking valleys. Innovation is highly concentrated (R. Florida, "The World is Spiky," *The Atlanta Monthly*, October 2005, pp. 48–51).

(e.g., ministry, bureau, or association), a defense-related organization, or a science park. A single instrumental player is the Chinese Academy of Sciences that alone administers some 100 research institutes.

Thousands of high-tech development zones exist in China today: some are no more than a facade for local authorities' real estate speculation or companies' pursuit of tax breaks and export subsidies; some serve their intended purpose and bring together innovative research, entrepreneurship, and venture capital, and are home to successful spin-off companies and small business incubators.[29] Furthermore, beginning in the early 1990s, National Engineering Research Centers (NERC) were established to accelerate the conversion of scientific research in to commercially viable products in several areas, among others electronics and microelectronics, computers, materials, agriculture, energy, and water resources.[30] As of April 2007, the some 140 NERCs were placed under the administration of the National Development and Reform Commission (NDRC).[31]

Science and technology policies are drawn up and overseen by governmental agencies of which the most influential are various leading groups under the State Council, MOST, Ministry of Finance (MOF), NDRC, Ministry of Education (MOE), Ministry of Agriculture, State Commission on Science and Technology for National Defense (COSTIND) and NNSF, the main funding agency of basic research (see Figure 1.5). Most of these entities operate at the central, provincial, and county level. Bureaucratically, on a "ministerial" level, is the prestigious Chinese Academy of Sciences; it is undergoing major reform and has a central role to play in China's technological aspirations.[32] The Chinese Academy of Engineering (CAE) is worth mentioning because many of its 600 academicians are influential policy advisors.

1.4.1.1 The role of enterprises

Enterprises are now proclaimed to have taken center stage of R&D in China. Statistically, R&D spending by enterprises has risen over the past decade. It accounted for 69 percent of China's R&D expenditure in 2005 (see Figure 1.6), which is proportionately on par with R&D spending by enterprises in industrialized countries.[33]

However, in terms of quality, the R&D capabilities of enterprises in China are weak, and it is "unlikely that many Chinese enterprises will develop R&D capabilities in support of novel, science-based technologies in the near future."[34] Leading CAS or key university-affiliated

Figure 1.6 Breakdown of China's R&D expenditure 2004–05.

	2004		2005	
Total expenditure (RMB 100m)	**1996.6**		**2450**	
Institutions	431.7	22%	513.1	21%
LMEs	954.4	48%	1250.3	51%
Universities	200.9	10%	242.3	10%
Others*	409.6	20%	444.3	18%

Note: * Mainly small enterprises.

Total enterprise expenditure (LME + small) constituted nearly 70% of total R&D in China, which is more than for example in the European Union (63%).

Source: OECD, MSTI 2006-2; *China Statistical Yearbook 2006*, pp. 825–827, 830.

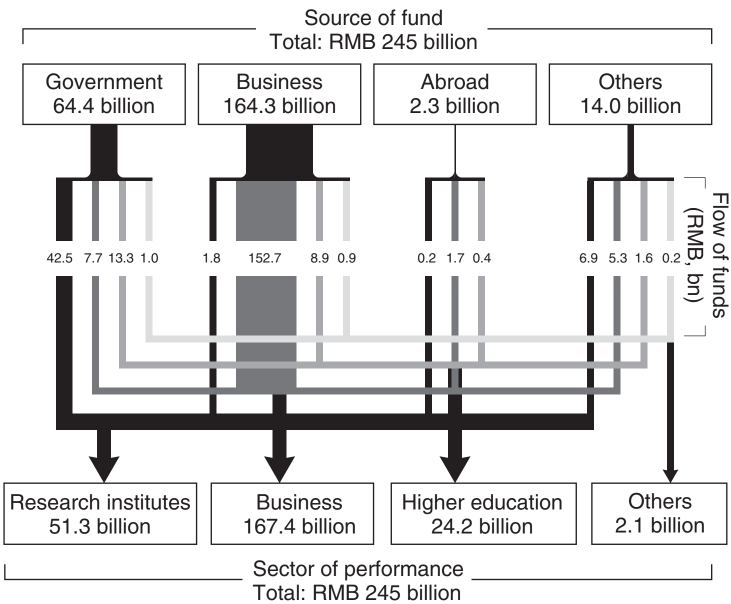
research institutes are in a stronger position to conduct innovative high-tech research in prioritized areas, with funding from government programs. Some of these institutes have partnered with high-tech companies. One much-publicized example is Lenovo (formerly Legend), a spin-off company of CAS that in 2004 purchased IBM's personal computer division.

Bearing in mind the focus of this chapter—China's capabilities to pursue innovative high technology research—it is noteworthy that Chinese companies have largely concentrated on product development with little emphasis on hard-core research. Of the 57,786 patents in the invention category that were approved in China in 2006, 43 percent were Chinese (57 percent granted to foreigners), while in the two other categories, utility models and design, 99 percent and 90 percent, respectively, were Chinese patents.[35] Large industrial enterprises spent nearly USD 5 billion in 2004 to purchase foreign technology but only USD 750 million to "absorb and assimilate" technology.[36]

Even the overwhelming majority of Chinese companies who are remarkable business success stories are not high-tech driven. Barring possibly a few solar energy technology companies, none of the top Chinese companies listed on Nasdaq stock exchange, for example, owe their rise to world-class, cutting-edge high technology.[37] Rather, they have mastered a competitive advantage in assembly, design, software, and/or systems engineering. This does not mean that they are merely assemblers, as Chinese companies are often labeled. They are being innovative even though they are not creating new core technology. These Chinese companies too spend on R&D (see Figure 1.7, also p. 54); thus, their input is reflected in data showing the increase of investment by enterprises into R&D.

Except for a few state-owned oil companies and successful non-state IT companies, R&D spending by Chinese companies is low by international standards. Over three-fourths of Chinese large- and medium-sized enterprises (LME) do not even have an R&D department! Total LME spending on R&D in 2005 accounted for 1.54 percent of LME sales revenue.[38] Only five Chinese companies made the list of the world's top 1250 companies in terms of R&D investment.[39]

Figure 1.7 Research and development expenditure flows, 2005.



The bulk of the Chinese government's research expenditure still goes to research institutes, for example, in 2005 research institutes received RMB 42.5 billion from the government, while universities received only RMB 13.3 billion.

Source: MOST, China Science and Technology Statistics Databook 2006, http://www.sts.org.cn/sjkl/kjtjdt/data2006/2006-1.htm; Figure adapted from Schwaag Serger and Breidne, "China's 15-year plan," see endnote 13.

There are multiple reasons for the low R&D investment by Chinese enterprises. When competition is fierce and profits are razor-thin, as is the case in many sectors in China, there is not much left over to invest. The growth of many Chinese companies has been based on cheap labor, a vast domestic market, and imported technology. Even if the technology has often been "second-hand"—not cutting-edge technology—it has been sufficient and has reduced the need for setting up in-house R&D.[40] Purchasing proven imported technology poses less risk than pursuing one's own technology, especially when IPR protection is extremely poor in China. Chinese companies tend to focus entirely on the short-term, reflecting a degree of uncertainty that the Chinese feel about their rapidly transforming society and the possible pitfalls that lie ahead. In addition, among Chinese enterprises and well-off consumers there has been and still is a preference for Western or Japanese technology vis-à-vis home-grown, although attitudes are slowly changing as a result of the success of a few Chinese companies producing world-class brands.

There are other factors that can be attributed to the weak R&D capabilities of Chinese enterprises. Non-state companies, for example, have been given few, if any, meaningful tax incentives to invest in R&D. Nor have they received preferential loans, as have state-enterprises, especially those targeted by the government to be national champions. It remains to be seen how much the innovation capabilities of non-state enterprises will improve toward the end of this decade, in line with the government's commitment in the 15-year S&T plan to provide fiscal support for all companies, regardless of ownership or size.

The main drawback of China's heavy reliance on technology transfer from foreign companies has been the limited spillover of technological know-how to Chinese partners or manufacturers. In the past, R&D centers set up by foreign companies were in private conversations referred to as "PR&D centers" because they were mainly established to create good will with the Chinese authorities and functioned predominantly as product development facilities.[41] However, there have been signs, at least in the pharmaceutical sector, that the tide is turning as multinational companies have started to pursue advanced, even basic research at their R&D centers in China.[42] Related to the question of little spillover from foreign enterprises is the weak record of Chinese efforts and/or capabilities to assimilate foreign technology. This is precisely the reason that the government is so resolute in its promotion of "indigenous innovation."

1.4.2 Human innovators

The basis of an innovative society is undoubtedly its human resources. This is often seen as China's chief asset when assessing its chances of becoming a techno-superpower, along with the steadily increasing investment being made in S&T and higher education. China has the world's second largest workforce of scientists and engineers, after the United States. In 2005, it numbered 2.5 million (vs. about 5 million in the United States and about 8.7 million in EU-25).[43]

1.4.2.1 Educating new talent

China has dramatically expanded university education over the last decade. In 1995, 450,000 Chinese were admitted to university. Ten years later, the number had risen more than fivefold.[44] In 2002, China reached the internationally recognized threshold of mass higher education, "15 per cent of the age cohort," with total enrollment of 16 million students.[45] Science and engineering majors are dominant; 43 percent of all undergraduates study S&E.[46] Noteworthy, however, is that data on S&E bachelor degrees vary greatly depending on the definition of degree. The figure often cited for the number of Chinese S&E graduates per year—600,000—includes at least 200,000 graduates of three-year technical institutes or training programs.[47]

Graduate programs have increased rapidly as well. Since the mid-1990s, graduate enrolments in Master's and PhD programs increased at 30 percent annually. In 2005, nearly 15,000 S&E doctorate degrees were conferred. The new enrolment figure for 2005 was 31,000, which puts China in a position to surpass the global leaders, United States, and Germany, in the number of S&E doctorates annually conferred (approximately 27,000 in the United States, 16,500 in Germany).[48]

Of course, quality matters too. Sheer volume will not make China a technological giant, a fact readily acknowledged by many Chinese education and S&T specialists. An assessment by McKinsey Global Institute evaluated only 10 percent of S&E undergraduates in China to be globally competitive in the outsourcing arena, on the basis of, among other factors, language proficiency and quality of education.[49] The lack of qualified staff is a common complaint among managers of multinational companies and globally oriented Chinese enterprises as well as directors of research institutions. China desperately needs more specialists who are well educated, talented, and able to maneuver within the unique PRC research system.

The quality of education provided in Chinese schools is one of the significant obstacles for China to achieve its goal of building an innovative-oriented society. First, the number of teachers has not increased to correspond with the huge increase in S&E graduates.[50] One professor can be responsible for supervising 75 PhD students. Second, most of the higher education enrolment growth of recent years is a result of burgeoning private education. The quality of education in private colleges varies greatly. Since 1999, public universities have been allowed to establish affiliated, so-called second-tier, for-profit colleges offering degree programs with less stringent entry requirements.[51]

Third, academic corruption in colleges and universities impacts the quality of education. In the last two years, there has been a barrage of articles, reports, and books published in the PRC about corruption linked to postgraduate recruitment, Master's and PhD thesis defense and evaluation, academic title qualification, thesis publishing, and so forth.[52] Furthermore, plagiarism is commonplace. This is, in part, a result of the enormous pressure on everyone, from Master's degree and PhD students to lecturers and professors, to publish academic papers in order to graduate, be promoted, or to receive research grants.

Above all, in spite of several educational reforms since the 1980s, teaching methodology, from primary school all the way to university, is still largely based on rote learning. While students in the PRC excel at tests, they tend not to be initiative takers, critical thinkers, or problem solvers. The Confucian tradition of deferring to authority is not conducive to creativity either. Even at elite universities, graduate students and young lecturers complain that the general atmosphere discourages anyone from questioning professors' views and compels PhD students and junior staff to pursue research according to established patterns with little room for innovative thinking.[53]

Despite the massive infusion of state funding to some forty key universities, it will be years before these institutions fulfill the government's goal of being considered world-class.[54] Most of the best Chinese universities have a few reputable professors and departments that provide high quality teaching and conduct meaningful research.

But two or three excellent departments do not yet make a university world-class. In 2006, not a single Chinese university made the internationally cited Shanghai Jiaotong University's ranking list of the world's hundred top universities.[55] Another widely used, British-compiled global list ranked two Chinese universities in the top hundred.[56]

Finally, the concentration of talent in a small pool drains the energy of the able. Those who are considered competent are given multiple responsibilities. The number of professional hats worn by a Chinese academic is often staggering (and usually evident from his or her business card). One cannot help wondering if any human being can simultaneously be a worthy professor with teaching commitments and the task of supervising several PhD candidates, a competent director of a research institute, an active vice-chairperson of two or three committees advising the government on S&T policies, a participatory member of the board of a university spin-off company, while at the same time keeping abreast of research developments in his or her own field of study and perhaps even publishing or contributing to research. Some or all tasks inevitably suffer. The list of positions tends to be longer if the person has been educated in the West.

1.4.2.2 Bringing back know-how

A cornerstone of Deng Xiaoping's opening policy was to allow Chinese to pursue studies abroad. In the early 1980s outbound students formed a trickle (about 5000 left in 1985) that grew into a steady flow during the 1990s (about 20,000 in 1995), which today resembles a tidal wave. In 2005 alone, nearly 120,000 Chinese went abroad to study.[57] The overwhelming majority of the over one million students who have gone abroad have relied on financial sources other than government funding.[58]

Since 1992, the government has actively tried to entice Chinese who pursued academic degrees and a career abroad to return to work in China. Scores of policies have been introduced to encourage and ease the return of overseas scholars and entrepreneurs. Numerous government programs provide financial support and assistance in finding jobs. Returnees who want to establish their own company are offered tax incentives and other preferential treatment, in some cases considerable support by top officials in securing start-up funding. In research institutes or enterprises they are paid, by Chinese standards, high salaries, and granted spacious housing, a prestigious title, and in some cases large funds to initiate research programs.[59]

Though the number of returnees has increased markedly in the 2000s (over 110,000 returned in 2001–05), hundreds of thousands who left China are still overseas. Many of them are still enrolled in schools abroad, but over 170,000 who no longer study have not returned.[60] This brain drain constitutes a genuine dilemma for the Chinese government. In all but a few fields, the most accomplished specialists have not returned.[61] Rather, returnees in recent years tend to be young BA or MA graduates, who find it difficult to find employment because they lack work experience.[62] The "100 Talents Program" of CAS, one of the most well-funded endeavors to encourage Chinese scholars to the PRC, managed to bring back 778 foreign-based Chinese researchers between 1998 and 2004. But only half had doctorates from foreign universities.[63] In the United States alone, there are 62,500 Chinese-born S&E PhDs who are green card holders;[64] the number doubled in merely four years.[65] This talent is sorely needed in China.

When reputable Chinese scholars do accept positions in China, they do so, nearly without exception, while continuing to hold on to their position abroad. This, in turn, has raised questions of how meaningful their input can be during brief visits to China. Several interviewees asked whether the commitment that a Berkeley or Stanford professor is willing to make for three months each year warrants the high salary and generous perks he is receiving from a Chinese institution.

For Chinese government officials who have publicly encouraged the return of overseas scholars, the question of why so few of the top Chinese researchers abroad have heeded their call is a sensitive one. The reasons for Chinese living overseas to return are manifold and readily discussed: besides the obvious lure of career opportunities in a growing economy and a society buzzing with energy, some make the move for patriotic reasons or because of a desire to care for aged parents or to ensure that their children are fluent in Chinese. There are multiple reasons to stay overseas too, but these are more awkward to expound on. To opt to return to a one-party authoritarian state where no one with certainty knows where the genuine boundary of freedom of speech lies is a leap into the unknown for many who have thrived in an open Western environment. Though the tragic ending of the

Tiananmen democracy movement in June 1989 does not figure in the minds of the under 35-year olds, the Chinese leadership's decision to use force is still mentioned in discussions about the returnee dilemma with middle-aged Chinese. China lost nearly a generation of its best-educated youth in the aftermath of the government crackdown. When, in April 1990, George H.W. Bush issued an executive order allowing Chinese who were in the United States in June 1989 to apply for permanent residency, about 60,000 took him up on the offer.[66] Especially for the Tiananmen generation of academics, the question "what if society does not remain stable?" still lurks in the subconscious.

In spite of the much-publicized efforts of Chinese officials to make the working and living environment suitable for returnees, returning to China after years abroad can prove difficult. On a personal level, life is often not as convenient as the one an academic, previously based in a Western university or research environment, is accustomed to. Returnees tend to feel alienated from their colleagues, partly because of envy stemming from high returnee salaries, but also because of their different outlook on life, based on the years spent abroad. Professionally, returnees within academia share their colleagues' frustration with the hierarchal and bureaucratic way institutions are managed, but are much less patient in expecting changes to take place. Those with working experience in the West find it hard to cope with the ever-present influence of politics in S&T decision-making and the top-down approach with which research institutes are managed. Those who are no longer citizens of the PRC feel slighted when they are barred from research funding (e.g., a major source of funding for S&T researchers, the 863 program, excludes foreign passport holders) and are not eligible to receive various national awards.

Some of the Chinese who have returned from abroad are without question a valuable addition to Chinese science, not only for the knowledge they bring back but also because they have established a network of international connections. However, many returnees have sought employment in multinational companies, which, in turn, is leading to a new kind of "internal" brain drain. Though some of the more adventurous among MNC returnees could one day make the break and start their own enterprises, for the most part, their value for China's S&T aspirations is modest.

While the status of overseas Chinese is complicated, their input is pivotal. Today, thousands of scientists with a Western academic degree and Western academic affiliation work alongside scientists with a solely domestic academic background. Some are citizens of the PRC; some are Taiwanese holding passports of the Republic of China (ROC); others were born in the PRC, then left the country for study and/or work and have returned to the PRC as foreign citizens; others are Overseas Chinese with much older roots abroad, that is they were born abroad and are of ethnic Chinese descent, either second-, third- or even fourth-generation Americans, Brits, Australians, Singaporeans, and so on. Culturally, they are all "Chinese." Yet, there are multilayered nuances of tension associated with their role in the PRC.[vi]

Overseas Chinese have constituted a pillar in the PRC's success. As investors and disseminators of Western technological know-how and management practices their role has been crucial. In the realm of S&T development and education, United States citizens of Chinese descent, in particular, have been instrumental. But though the input of Overseas Chinese is welcomed by PRC officials, it is unclear how these "Chinese compatriots." as they are called in official context, fit in to the government's larger scheme of promoting "indigenous innovation" in order to make China a technological world power. If groundbreaking research is done in a laboratory, situated in the PRC, by a team headed by an American citizen, does this qualify as "indigenous" research? And, if that research is awarded a Nobel Prize, will China claim credit?[67] Also, issues of IPR have yet to be addressed. How do the Chinese and foreign institutions that a head scientist is affiliated with share IPR? It is not inconceivable that if political tensions were to rise between China and Western countries, American and European funding institutions may question where and for whose purposes grant money has been used.

An illuminating example of the confusion and possible misunderstanding that can arise from multiple identities is an April 2006 *People's Daily Online* article, headlined "World's smallest generator developed in China." It fails to mention that the research was done at the Georgia Institute of Technology by a prominent American nanoscientist of Chinese heritage. The scientist was born in the PRC.

[vi] The term for "China" in Mandarin—*Zhong guo* or *Zhong hua*—can mean the country China, but also the Chinese civilization or culture.

In addition to his main job in Atlanta he is a part-time director of a leading nanoresearch center in Beijing.[68]

Naturally, similar questions apply in other countries as well. The globalization of research is becoming the norm, alongside the two-way flows of "transnational capital."[69] and the establishment of "transnational communities" and "global production networks."[70] However, in China, the contradictory position of Overseas Chinese is especially relevant because of, on the one hand, the vital role of the large community of foreigners of Chinese heritage working in the PRC and, on the other hand, the PRC government's emphasis on "indigenous innovation."

1.5 The domestic environment

Throughout the reform period, the leaders of the Chinese Communist Party have made efforts to reform the inner workings of the Party to improve its capabilities to govern China. However, many systemic problems still hamper S&T progress.

1.5.1 Linkages

The so-called stovepipe syndrome that has its roots in the centrally planned economy still plagues China's S&T landscape. Each research entity tends to be an isolated work unit, an island on its own. Even research centers of multinational companies have few ties to the research community at large. Collaboration among research institutes or universities has traditionally been weak, and the same applies to ministries, other government organizations, and state-owned enterprises (this problem affects modernization processes within Chinese society more broadly). In part, this is a legacy of the past, as mentioned earlier. In part, it derives from the present, rigid top-down political system as well as from fierce competition for government funding, talented people, and ultimately, power within the system. In numerous plans and policy outlines, the government encourages cooperation, especially between research institutes and enterprises. In reality, weak linkages remain a major structural challenge.

An obvious consequence of weak collaboration between different entities is that China's limited "scientific resources are scattered, repetitive, and not used efficiently."[71] There is tremendous waste within the system (again, this applies more broadly to Chinese society). Lack of communication between research entities is often accompanied by mistrust, which does not promote the free exchange of ideas. Of course, within academia worldwide rivalry related to funding opportunities are commonplace. The problems are accentuated in China because of the unclear way in which funding decisions are made. When decision-making processes are not transparent and decision-makers are not accountable on the basis of publicized rules that can be challenged, cultivation of personal relations with decision-makers is essential. In research interviews probing the S&T landscape in China, a recurring spontaneous observation was the need for Chinese to study effective system management.

1.5.2 Other systemic problems

The bureaucratic control mentality, inherited from the planned economy, is one of the greatest hurdles China has to overcome in order to transform into a world-class innovative society. The fact that the 15-year S&T plan ended up including four science megaprojects and sixteen engineering megaprojects reflects the bureaucrats' dominance (see Figure 1.8). In the drafting stages of the plan, both behind closed doors and in a few cases in public, several leading scientists made known their staunch opposition to continue the legacy of heavy-handed science planning in the spirit of *liangdan yixing* , the nickname of the 1956–67 program that led to China acquiring nuclear weapons and building satellites.[72] But to no avail.

In four-fifths of the research interviews conducted for this chapter, the Ministry of Science and Technology, in particular, was criticized for its inept bureaucrats, for its attempts to control the direction of research, for its lack of transparency in decision-making, as well as for its over-spending on infrastructure and "mammoth projects that give bureaucrats a lot of face." When asked about the role of Minister of Science and Technology Xu Guanhua, a specialist in remote sensing, several interviewees answered that one person cannot change the top-down approach of a ministry that has its roots in the old central-planning system.* "The system is stronger than the person, and the person is molded," a mid-level MOST official said. Several interviewed researchers opined that the only remedy would be the abolishment of MOST and the establishment of a new government body to oversee S&T policies, one based on modern concepts of openness and accountability.

* In April 2007 Xu resigned at age 66 and was replaced with 55-year old Wan Gang, President of Tongji University in Shanghai. Wan is a fuel cell specialist who in 1991 received his PhD in mechanical engineering in Germany before pursuing research at Audi Corporation.

Figure 1.8 Mega projects of the "Medium- and Long-term S&T Development Plan."

Mega science projects (4)	**Mega engineering projects (13)***
Protein Science	Core electronic components, high-end generic chips, and basic software
Quantum Research	Extra large scale integrated circuit manufacturing and technique
Nanotechnology	New-generation broadband wireless mobile telecommunications
Development and Reproductive Biology	Advanced numeric-controlled machinery and basic manufacturing technology
	Large-scale oil and gas exploration
	Large advanced nuclear reactors
	Water pollution control and treatment
	Genetically modified new-organism variety breeding
	Drug innovation and development
	Control and treatment of AIDS, hepatitis, and other major diseases
	Large aircraft
	High-definition Earth observation systems
	Manned aerospace and Moon exploration

Note: * The S&T plan states that there are 16 mega engineering projects, but then proceeds to give details for only 13. One can surmise that the remaining three deal with national defense.

The detailed action plan to implement the 15-year S&T plan indicates that MOST will no longer be the main government body in charge of S&T development in China. The role of MOST remains important, but it shares responsibility for implementing the 15-year S&T plan with, among others, MOF, NDRC, and MOE.[73] Implementation of the 15-year S&T plan requires close cooperation between ministries and between central and local government entities—that is a tall order in today's China.

Another major stumbling block is law enforcement, that too a symptom of the systemic problems that the Chinese leadership is grappling with as it attempts to prepare China for the challenges of the twenty-first century. Lack of law enforcement in the realm of S&T translates explicitly into weak enforcement of IPR. Pirating of intellectual property is rampant. Many experts see this as the paramount problem that will deter China from achieving it goals.[74] China will not be looked upon as a favorable location to conduct groundbreaking research before researchers, both Chinese and foreign, can trust the system to protect IPR.

Academic misconduct, including corruption and plagiarism, are systemic problems too. A revealing book written by Professor Liu Ming of Zhejiang University about academic corruption in China documents in detail the customary practices and sums involved in bribing Master's degree and PhD thesis committee members, purchasing academic titles as well as the buying and selling of academic papers. According to Liu, academic corruption is a "typical 'fish rot' syndrome that not only poisons the social environment, but also decays the souls of [future] generations."[75] Liu traces the problems of Chinese science and academia to China's political system, specifically political interference at all levels and the lack of independent organizations. He argues that political interference prevents the peer review system from functioning properly. Lack of reliable qualitative evaluations pushes universities and Chinese science to rely too much on quantitative indicators.

1.6 The international environment

Foreign investment, foreign technology, and foreign expertise have constituted strategic gears of China's modernization drive for over 25 years. They will continue to do so. International research cooperation has been instrumental for China's S&T development. There is every reason to predict that this too will play a significant role in the future. China will further expand its transnational knowledge networks, including tens of thousands of formal and informal types of research cooperation between Chinese and foreign governments, universities, research institutes, and companies, as well as individual researchers.

However, as the global economy moves toward a knowledge-based economy in which the role of technological innovation is central, the economic strength of a nation will increasingly be determined by who owns the technology. Those who control IPR and set technology standards of new products increase their competitiveness. Hence the need for Chinese companies to improve their own innovation capabilities and avoid paying license and royalty fees to foreigners.[76]

The Beijing government aspires to China developing its own standards, at least in prioritized areas. China's national standards strategy advocates that inventions resulting from "indigenous innovation" translate into Chinese standards incorporating Chinese intellectual property. On the other hand, it is not clear whether Chinese enterprises share this goal. They, after all, must adhere to international standards to be competitive in the global market.[77]

China has an additional incentive to strengthen its R&D capabilities: It is restricted from acquiring some so-called dual-use technology because of export controls imposed by the United States and the European Union. Most of these controls were put in place following the Chinese government's suppression of the Tiananmen movement in 1989. The restrictions further strengthen the view among some Chinese policy-makers that outsiders, in particular the United States, are intent on containing China's rise. An example worth mentioning in this context is the consternation among Chinese policy-makers over the U.S. decision in March 2006 to sign a nuclear cooperation agreement with India. Chinese officials interpreted the move as directed against China, which reinforced their view that China must find a way to rely on its own "indigenous" high technology.[78]

In sum, Chinese decision-makers look upon the international environment as both furthering and hindering China's S&T ambitions. As has been the case since the economic reform and opening policies were embraced, the pull-and-push between internationalist and nationalist views among leading Chinese policy-makers is bound to continue. Hence, the balancing of techno-nationalist and techno-globalist objectives will remain a dominant feature of S&T policies in China. China will pursue multiple paths to achieve its goals.

1.7 Conclusion

China has several of the drivers in place to fulfill its technological ambitions. The political elite and scientific community are committed, the government is willing to provide substantial funding to S&T, and the general public approves of placing a high priority on S&T.[79] The speed with which China has acquired the ability to build high quality research and knowledge centers has been phenomenal. A handful of Chinese companies such as Hai'er, Huawei, and Suntech (Shangde) have become world leaders in their own sectors.

However, for a strong national innovation system to emerge in China, four main obstacles need to be overcome. These are raising the quality of Chinese education; reducing the bureaucratic control of S&T policy-makers to facilitate an environment conducive to creativity and cooperation; improving law enforcement to protect IPR; and implementing a system of checks-and-balances to introduce accountability for grant applications, job promotions, thesis approvals, and academic articles. Needless to say, there are numerous other problems China needs to tackle. Many of them are being addressed with targeted policy measures. Chinese leaders are acutely aware of the problems. The inefficient and inappropriate management of research funds is a recurring theme in governmental reports and speeches.[80]

The underlying question is whether a state in which freedom of speech is restricted and stability is placed at the very top of the government's priority list can transform itself into an innovation-oriented society. Can creativity and innovation flourish in an environment that ardently deters people from rocking the boat? That constantly reminds people that the ultimate goal is a harmonious society? That is known to hammer down the nail that sticks out?[vii] The goal of building a harmonious society is a repackaging of the demand for stability.[81] How does one encourage students to challenge authority in the science classroom and prod researchers to disregard recognized models, while simultaneously demanding that they do not question the rules that govern society? These are complex questions to which there are no definite answers. The continuous success of PRC-born students within academia in the United States and Europe is proof of the capabilities of Chinese researchers when they work in an academic atmosphere in which diversity and critical thinking are cherished.

The efforts that China has made and continues to make toward technological excellence will certainly bear fruit. Within the next decade, in some cases perhaps sooner, there will be news of groundbreaking innovative research done in China. There are several pockets

[vii] There are several corresponding Chinese sayings, for example, "The taller the tree, the more wind it attracts;" "A person fears fame, a pig fears becoming stout."

of excellence within such fields as information technology, biotechnology, nanotechnology, and perhaps some other fields of science. But, considering the enormity and extent of the major hurdles China has to overcome to build a comprehensive national innovation system, it is highly unlikely that the transformation could take place in 15 years.

China will proceed to develop its capabilities in the realm of S&T in the same manner it has traversed the reform road since 1978, bit by bit, one step at a time, striving to instill in future generations of Chinese scientists what Premier Wen Jiabao has referred to as an "innovative spirit."[82] Changes will be implemented incrementally. Progress will be piecemeal. At the end of the day, whether or not China achieves its ambitious goals in the realm of S&T depends on how societal reform in China progresses. The S&T landscape faces the same problems as society at large.

Notes

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2. "Chinese President stresses urgency of 'shifting economic growth mode,'" *People's Daily Online*, 17 January 2006, http://english.peopledaily.com.cn/200601/17/eng20060117_235924.html.
3. The target of quadrupling the 2000 level GDP by 2020 was articulated at the Sixteenth Party Congress of the CPC in November 2002. "China to Quadruple GDP in 2020 from 2000," *People's Daily Online*, 8 November 2002, http://english.peopledaily.com.cn/200211/08/eng20021108_106504.shtml.
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6. "China outlines strategic tasks for building innovation-oriented society," *People's Daily Online*, 9 January 2006, http://english.peopledaily.com.cn/200601/09/eng20060109_233967.html.

7. "President Hu calls on scientists to help achieve goal of innovation nation," *People's Daily Online*, 6 June 2006, http://english.peopledaily.com.cn/200606/06/eng20060606_271360.html.
8. Author's research interviews during 2006. See also M.M. Poo, "大科学和小科学" [Big Science, Small Science], *Nature*, 432, China Supplement (18 November 2004), pp. 18–23; Y. Rao, B. Lu, and C.L. Tsou, "中国科技需要的根本转变：从传统人治到竞争优胜体制" [A Fundamental Transition from Rule-By-Man to Rule-By-Merit: What Will be the Legacy of the Medium- and Long-term S&T Development Plan?], *Nature*, 432, China Supplement (18 November 2004), pp. 12–17; Poo, "Cultural reflections," *Nature*, 428, English-language China supplement, (11 March 2006), pp. 204–205; R. Wu, "Making an Impact," *Nature*, 428, English-language China supplement, (11 March 2006), pp. 206–207. The November 2004 *Nature* supplement in Chinese was initially quoted in the PRC media until its distribution was banned in China, and Chinese editors were allegedly told not to refer to it nor comment on the draft of the 15-year S&T plan (X. Hao and Y.D. Gong, "China Bets Big on Big Science," *Science*, 311 (17 March 2006), p. 1549).
9. State Council of the People's Republic of China, "国家中长期科学和技术发展规划纲要" [Outline of National Medium- and Long-term S&T Development Plan (2006–2020)], 9 February 2006, http://www.gov.cn/jrzg/200602/09/content_183787.htm. The English translation of the plan is a 23,000-word document, see for example Xinhua (New China News Agency), "Text of PRC Medium- and Long-term S&T Program Guidelines for 2006–2010," 9 February 2006 (English translation by Open Source Center).
10. According to MOST, reliance on foreign technology is calculated using the following index: reliance on foreign technology = expenditure on importing foreign technology / (domestic R&D expenditure + expenditure on utilizing domestic technology + expenditure on importing foreign technology). See question posed by Yu Fengliang on 17 August 2006 at link: http://appweblogic.most.gov.cn/gzwd/gzwd_jsjg.jsp?Tid2=002&page=28.
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13. These advantages were all mentioned in the draft of the revised S&T Progress Law under consideration in early 2007. Ministry of Science and Technology, "法制办就科学技术进步法（修订草案）征求意见" [Legal Office seeks opinions on the revised draft of the S&T Progress Law], 22 March 2007, http://www.most.gov.cn/yw/200703/t20070326_42340.htm.

14. Ministry of Science and Technology, "创新型企业试点工作初见成效" [Preliminary results of the pilot project on innovative enterprises], 26 February 2007, http://www.most.gov.cn/kjbgz/200702/t20070226_41515.htm.
15. S. Schwaag Serger and M. Breidne, "China's 15-year plan for science and technology—a critical assessment," paper presented at conference "New Asian Dynamics in Science, Technology and Innovation," Gilleleje, Denmark, 27–29 September 2006, p. 15.
16. China has not yet signed the Government Procurement Agreement (GPA). Until it joins the GPA, China is technically not obligated to refrain from protecting its domestic industries. Upon joining the GPA, however, it then must not discriminate against foreign suppliers above certain thresholds and within the sectors/entities covered in the agreement, but can continue to do so in those areas not covered. China committed to join the GPA as soon as possible in its WTO Accession Protocols (author's correspondence with Louisa Chiang of the Trade Facilitation Office at the U.S. Embassy in Beijing, 14 February 2007).
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22. Research interview with senior Chinese academic who serves on several governmental advisory committees, Beijing, 25 April 2006. For a discussion of the controversy surrounding *zizhu chuangxin* and the Chinese academic community's reactions to the new policy emphasis, see L. Jakobson,

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23. Jiang Zemin's speech at "Chinese National Conference on S&T," 26 May 1995. Quoted in http://www.globalsecurity.org/military/library/report/1996/stpol1.htm.
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26. Author's research interviews with eleven MOST officials, 3 January–24 September 2006.
27. B. Naughton and A. Segal, "China in Search of a Workable Model. Technology Development in the New Millennium," in W.W. Keller (ed.), *Crisis and Innovation in Asian Technology* (West Nyack, NY: Cambridge University Press, 2003), p. 162.
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32. For an overview of the Knowledge Innovation Program, an ongoing reform process of the Chinese Academy of Sciences, see R.P. Suttmeier, C. Cao, and D.F. Simon, "China's Innovation Challenge and the Remaking

of the Chinese Academy of Sciences," *Innovations* (Summer 2006), pp. 78–97.
33. Ministry of Science & Technology, "RMB 245 Billion R&D Expenditure," Newsletter no. 451, 20 September 2006. http://www.most.gov.cn/eng/newsletters/2006/200610/t20061027_37210.htm; OECD, *Main Science and Technology Indicators*, December 2006.
34. See Suttmeier, Cao, and Simon, "China's Innovation Challenge," p. 80.
35. State Intellectual Property Office, "Grants for Three Kinds of Patents Received from Home and Abroad," 15 January 2007, http://www.sipo.gov.cn/sipo_English/statistics/gnwsqnb/2006/200701/t20070115_126914.htm.
36. "经济观察：九大问题挑战 '创新型国家'" [Economic observations: Nine big questions challenging an "innovative nation"], *Renmin Ribao* [People's Daily], 9 January 2006.
37. Research interview with Professor Martin Kenney who has done extensive research on venture capital markets, San Francisco, 29 March 2006.
38. National Bureau of Statistics of China, *China Statistical Yearbook 2006*, (Beijing: China Statistics Press), p. 827.
39. The five Chinese companies to make the list: PetroChina (185), China Petroleum & Chemical (260), ZTE (298), Semiconductor Manufacturing (701), CNOOC (963). Department of Trade and Industry (U.K.), "The R&D Scoreboard 2006," vol. 2, p. 84, http://www.innovation.gov.uk/rd_scoreboard/. It is worth noting that Huawei spends more on R&D than any Chinese company that made the list; the RDI Scoreboard is based on survey results, so it is possible that Huawei simply did not answer the survey. Moreover, Semiconductor Manufacturing is majority foreign-owned.
40. S.L. Gu and B-Å. Lundvall, "Policy Learning in the Transformation of the Chinese Innovation Systems," in Lundvall, P. Intarakumnerd, and J. Vang (eds.), *Asia's Innovation Systems in Transition* (Cheltenham: Edward Elgar Publishing Ltd, 2006), p. 301.
41. A study headed by the Science Counselor of the Swedish Embassy in Beijing estimated that only 30 large MNCs were conducting innovative research in China. S. Schwaag Serger, "From Shop Floor to Knowledge Factory," in M. Karlsson (ed.), *The Internationalization of Corporate R&D, Leveraging the Changing Geography of Innovation* (Öresund: The Swedish Institute for Growth Policy Studies, 2006), p. 245, http://www.itps.se/Archive/Documents/Swedish/Publikationer/Rapporter/Allm%C3%A4nna/A2006/Kap10_A2006_007.pdf.
42. Copenhagen-based Novo Nordisk, the first multinational pharmaceutical company to open an R&D center in China, was a pioneer and, from its establishment in 2001, assigned its Beijing center tasks including basic research in genetic engineering of bacteria and antibody technology (correspondence with E. Boel, Vice-President, Novo Nordisk, 7 November 2006). In late 2006, Boston-based Novartis announced it would conduct basic scientific research in China, by investing USD 100 million in a new drug discovery facility in Shanghai (G. Dyer, "Novartis to open research facility in China," *Financial Times*, 6 November 2006).

43. The size of the S&E workforce naturally varies based on the criteria used to define scientist or engineer. The figure for China is for "scientists and engineers engaged in R&D activities" in 2005 (*China Statistical Yearbook 2006*, p. 825). The U.S. figure 4.9 million is for "those in S&E occupations with at least a bachelor's degree" in 2003 (NSF *Science and Engineering Indicators 2006*, Table 3–5). The EU-25 figure is from Eurostat, "Measuring gender differences among Europe's knowledge workers," *Statistics in Focus, Science and Technology*, 12/2006, p. 3, http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-NS-06-012/EN/KS-NS-06-012-EN.PDF.
44. *China Statistical Yearbook 1996*, p. 634; *2006*, p. 803. The figure 450,000 is for new admissions to four-year undergraduate programs. In addition, 480,000 new students were admitted to "colleges for professional training" in 1995; 2,680,000 in 2005.
45. R. Hayhoe and Q. Zha, "Becoming World Class: Chinese Universities Facing Globalization and Internationalization," *Harvard China Review* (Spring 2004), p. 88.
46. *China Statistical Yearbook 2006*, p. 805.
47. *China Statistical Yearbook 2005*, p. 697 gives the figure 576,627 for S&E graduates from undergraduate programs in 2004. According to a Duke University study, in 2004 China awarded 376,415 bachelor degrees in engineering, computer science, and information technology, compared to 137,437 in the United States and 139,000 in India (G. Gereffi, V. Wadwha, and B. Rissing, "Framing the engineering outsourcing debate: comparing the quantity and quality of engineering graduates in the United States, India and China," paper prepared for SASE 2006 conference "Constituting Globalisation: Actors, Arenas, and Outcomes," in Trier, Germany, 27 June 2006, pp. 6–8).
48. Data for Germany from 2003. Science and Engineering doctorates conferred in Britain 8810 (2003); Japan 7581 (2003); Finland 922 (2002); in EU-14 (Luxembourg missing) 40,776 (2002). Data for China from *China Statistical Yearbook 2006*, p. 802; 2005, p. 694. All other data from NSF *Science and Engineering Indicators 2006*, Tables 2–40, 2–42.
49. McKinsey Global Institute, "The Emerging Global Labor Market: Part 1—The Demand for Offshore Talent in Services," June 2005, p. 24.
50. See Y. Lin, "The Grim Situation in China with Regard to Building a Teacher Base and Rejuvenating the Higher Education System," *Chinese Education and Society*, 38: 4 (July/August 2005), p. 33; see also Gereffi, Wadhwa, and Rissing, "Framing the Engineering," pp. 14–15.
51. World Education News and Review, "International Rankings and Chinese Higher Education Reform" (New York: World Education Services, October 2006), http://www.wes.org/ewenr/PF/06oct/pfpractical.htm.
52. For a comprehensive overview on academic corruption in China, see chapter 2 ("Criticism of Academic Morality," pp. 13–26), in book by Professor Liu Ming of Zhejiang University: 刘明, 学术评价制度批判 [Criticism of the Academic Evaluation System], 长江文艺出版社 [Changjiang Literature and Art Publishing House], 2006. I am grateful to David Cowig for pointing out this enlightening book. See also "高校的非典型腐败"

[Abnormal corruption of higher education] 中国新闻周刊 [*Newsweek*, Chinese edition], 20 March 2006.
53. Since 1988 to the present, the author has regularly either conducted research interviews or had informal discussions about the quality of teaching and educational reform at five of China's top ten universities: Beijing, Tsinghua, Fudan, Zhejiang, and Renmin University. See also e.g. P. Mooney, "The Long Road Ahead for China's Universities," *Chronicle of Higher Education*, 52: 37 (19 May 2006), pp. 51–52.
54. Nearly 40 universities presently receive prioritized government funding via "Project 985" that aims to hasten their transformation into world-class universities. In May 1998, "985" was founded and supplemented the Chinese government's earlier "211 program," intended to aid 100 universities to achieve world-class status, by providing even greater funding (see World Education News and Review, "International Rankings.") Furthermore, one of the goals of the Knowledge Information Program of CAS is to create 30 internationally recognized research institutes by 2010, with five recognized as world leaders (see Suttmeier, Cao, and Simon, "Knowledge Innovation," p. 58).
55. "Academic Ranking of Top 500 Universities 2006." Because of its methodology emphasising S&T, the Shanghai Jiaotong University list ranks almost exclusively research universities and not liberal-arts colleges: http://ed.sjtu.edu.cn/rank/2006/ARWU2006_Top100.htm.
56. "THES-QS World University Rankings 2006/07," published by the *Times Higher Education Supplement*. Beijing University ranked 14th, Tsinghua 28th: http://www.topuniversities.com/worlduniversityrankings/results/2006/.
57. *China Statistical Yearbook 2006*, p. 801.
58. For an overview of funding of overseas students, see C. Li, "Coming Home to Teach: Status and Mobility of Returnees in China's Higher Education," in C. Li (compiled), *Bridging Minds across the Pacific* (London: Lexington Books, 2005), p. 77. The figure over one million for total students who have left China to study abroad by the end of 2006 is an estimate based on *China Statistical Yearbook 2006*, p. 801 and MOE report "2005年留学工作年鉴" [Overseas Students' Work Report 2005], http://www.moe.gov.cn/edoas/website18/info12181.htm.
59. For an overview of Chinese government policies to reverse the brain drain, see D. Zweig, "Competing for Talent: China's Strategies to Reverse the Brain Drain," *International Labour Review*, 145: 1–2 (2006), pp. 65–78.
60. Over 540,000 students left China for study abroad 2001–05 and could not be expected to have finished their degrees yet (*China Statistical Yearbook 2006*, p. 801). The figure 170,000 is from returnee data up till end of 2003 (MOE report "Work Related to Students and Scholars Studying Abroad," http://www.moe.gov.cn/english/international_2.htm).
61. Several China-based academics as well as Chinese S&T officials put forward this stance in research interviews conducted by the author in China during 2006. See also Zweig, "Competing for Talent," pp. 78–80; Wildson and Keeley, "China: The Next," p. 29.

62. Personal correspondence with David Zweig, 7 January 2007.
63. See Suttmeier, Cao, and Simon, "China's Innovation Challenge," p. 83.
64. The author first became aware of this figure during the power presentation of R.P. Suttmeier and C. Cao at China–U.S. Forum on S&T Policy, Beijing, 16 October 2006. The figure, based on 2003 data, is from *NSF Science and Engineering Indicators 2006*, Table 3–18.
65. Data from 1999. European Commission, "European PhD holders in the U.S.," Third European Report on S&T Indicators 2003, March 2003, ftp://ftp.cordis.europa.eu/pub/indicators/docs/3rd_report_snaps3.pdf.
66. L. Jakobson, *A Million Truths. A Decade in China* (New York: M. Evans, 1998), p. 258. Furthermore, about 11,000 mainland Chinese students in Canada received permanent residency.
67. For a discussion of the "Nobel Prize mania" in China, see C. Cao, "Chinese Science and the 'Noble Prize Complex'," *Minerva*, 42 (2004), pp. 151–172.
68. "World's smallest generator developed in China," *People's Daily Online*, 25 April 2006, http://english.people.com.cn/200604/25/eng20060425_261054.html; Z.L. Wang and J.H. Song, "Piezoelectric Nanogenerators Based on Zinc Oxide Nanowire Arrays," *Science*, 312 (14 April 2006), pp. 242–246.
69. S. Rosen and D. Zweig, "Transnational Capital: Valuing Academic Returnees in Globalizing China," in C. Li (compiled), *Bridging Minds across the Pacific* (London: Lexington Books, 2005), p. 112.
70. A.L. Saxenian, "Transnational Communities and the Evolution of Global Production Networks: The Cases of Taiwan, China, and India," *Industry and Innovation*, 9: 3 (December 2002), pp. 183–202.
71. Y. Zheng and M.J. Chen, *China Plans to Build an Innovative State* (Nottingham: China Policy Institute, University of Nottingham, June 2006), p. 12.
72. Author's research interviews with 12 Chinese who participated in the drafting of the 15-year S&T plan, 1 November 2005–15 January 2007; three of the interviewees were involved in the final stages of the plan's approval process. See also Poo, "大科学和小科学" [Big Science, Small Science], pp. 18–23; Hao and Gong, "China Bets Big on," pp. 1548–1549.
73. "国务院办公厅关于同意制订《实施〈国家中长期科学和技术发展规划纲要〉的若干配套政策》实施细则的复函" [Letter of reply by General Office of the State Council regarding the approved formulation of list of detailed rules and regulations for "Implementing a number of policies for the 'National Medium- and Long-term S&T Development Plan'"], http://www.gov.cn/gongbao/content/2006/content_310755.htm. The first installment of support policies were published four months after the 15-year S&T plan was officially unveiled. The NDRC was assigned responsibility for 29 so-called support policies, the MOF for 21, MOST for 17, and the MOE for 9. For a discussion of the 15-year S&T plan's supporting policies and role of MOST, see Schwaag Serger and Breidne, "China's 15-year plan," pp. 10–14.

74. See for example A. Stevenson-Young and K. DeWoskin, "China Destroys the IP paradigm," *Far Eastern Economic Review*, 168: 3 (March 2005), pp. 9–18.
75. See M. Liu, 学术评价制度批判 [Criticism of the Academic Evaluation System], p. 16.
76. For a detailed discussion of China's national standard strategy, see R.P. Suttmeier, X.K. Yao and A.Z. Tan, *Standards of Power? Technology, Institution, and Politics in the Development of China's National Standards Strategy* (Seattle: National Bureau of Asian Research, June 2006), pp. 1–16, 28–39.
77. Discussions with Chris Lanzit who works in the field of standards as Executive Director of the Beijing office of Consortium of Standards and Conformity Assessment (CSCA) that encompasses four U.S.-based standards development organizations (API, ASME, ASTM International, and CSA America). See also p. 46 and pp. 65–66 in Chapter 2. Suttmeier, Yao, and Tan also allude to competing interests [of enterprises] that do not necessarily coincide with the political will of policy-makers (see Suttmeier et al., *Standards of Power?* p. 37).
78. The historic pact on nuclear cooperation between the United States and India, which commits the United States to share nuclear reactors, fuel, and expertise with India, was announced on 2 March 2006 when the author was conducting research interviews in Shanghai. Both in Shanghai and during discussions with S&T officials during the following weeks in Beijing, the U.S.-India deal was brought up by the interviewees as proof of the U.S. intent to contain China's rise.
79. See R. Silberglitt, P.S. Anton, D.R. Howell, and A. Wong, "The Global Technology Revolution 2020, In-Depth Analysis," National Security Research Division, Rand Corporation, 2006, pp. 78–83.
80. For example, a progress report published by MOST in January 2007 reflected the government's dissatisfaction with the inefficient use of resources allocated to R&D. According to the report, progress in the previous 12 months had been modest despite a substantial increase in government funding (MOST, "徐冠华部长在 2007 年全国科技工作会议上的报告" [Minister Xu Guanghua's Report at the National S&T Work Conference 2007], 29 January 2007, http://www.most.gov.cn/tztg/200702/t20070209_41241.htm). Moreover, during the National People's Congress in March 2007, a lawmaker accused top universities of misusing research funds to build luxury buildings (H.P. Jia, "Top Chinese universities 'mis-spending' funds." SciDev.Net, 8 March 2007, http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=3465&language=1).
81. I am grateful to Denis Fred Simon for reminding me of the parallel.
82. See, e.g., Graduate School of CAS, "温家宝强调：要把教育摆在优先发展的战略地位" [Wen Jiabao emphasizes: Education must be given strategic status in order to enhance development], 29 November 2006, http://news.gscas.ac.cn/info_www/news/detailnewsb.asp? infono=8579.

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