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Will China Become a Science and Technology Superpower by 2020?

An Assessment based on a National Innovation System Framework

Becoming a full-fledged member of the 21st knowledge economy through the absorption and creation of new knowledge, particularly in science and technology (S&T), has become a major national priority for China, comprising an important element of future national development. Since China's opening up to the outside world in the late 1970's, government policies have promoted a more liberalized, market economy, and a strengthening of the national innovation system to foster scientific research and technology acquisition. The seriousness of this commitment is evidenced by the new comprehensive plan for S&T development for 2006-2020 unveiled at the National Science and Technology Congress in January 2006. The plan was prepared under the leadership of Premier Wen Jibao and State Councilor Chen Zhili from 2003 to 2005. Over 3000 experts in natural sciences, engineering, and social sciences participated in the planning process.

Reforms over the last few decades have entailed major revamping of S&T

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institutions and policies, moving from a centralized, highly controlled Soviet-style model to a more autonomous, entrepreneurial, market-based model. Other governmental strategies have included allocating increased funds for domestic R&D programs, and actively encouraging international cooperation in S&T activities as well as foreign direct investment in R&D through various incentive programs.

The desired end result of these efforts would be a world class S&T industrial base, with the infrastructure, private and public sector R&D capabilities, and educational institutions equal to those in the developed world. It would be capable of world-class technological innovation, producing a broad range of products and patents traded and licensed in global markets. It would boast cutting-edge capabilities in critical areas such as biotechnology, micro-electronics, telecommunications, advanced materials, aerospace, advanced manufacturing and information technology, as well as a highly-skilled science and engineering workforce.

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China also needs to build up its S&T base in order to meet its goal of quadrupling its Gross Domestic Product (GDP) by 2020, and to address urgent energy, environmental, and public health challenges. The country is also striving to develop a business workforce skilled in design, production, marketing, distribution, advertising, sales and corporate know-how in order to compete in the 21st century knowledge economy. Given today's global inter-connectedness, the rest of the world should have a great interest in how China's science and high-technology industrial base—currently a geographic and technological patchwork—will adapt to the needs of a changing society, the increasing globalization of S&T, and the challenges of developing truly innovative, indigenous, intellectual and R&D capabilities.

Despite its recent high technology growth, overall the country is still far from achieving its goals. China has to create 10 million new employment opportunities every year for people who join the labor market. While the official unemployment rate hovers around 4-5%, the real unemployment rate is much higher if one takes into account those who lost their jobs as the result of the privatization of state-owned enterprises and the extra labor in the countryside—millions of whom have come to the cities trying to find jobs. If current high-technology growth cannot translate into concrete economic opportunities, the enthusiasm surrounding it will sooner or later lose steam.

Other challenges entail being able to accommodate the considerable institutional variety which one now sees in Chinese industry, as well as great regional disparities. Chinese firms must learn to assume the expenses and risks of innovation on their own, independent of government support, and develop the managerial expertise needed for effective corporate innovation, along with the best practices, independent spirit and respect for intellectual property so important for today's sophisticated high technology innovations.

Many observers state that China has the potential to become a major global high-tech superpower. To make sense of this prediction one must first understand the nature and style of China's national innovation system as it evolves and adapts to a fast-paced domestic and international marketplace and to new government reforms. The national innovation system framework is a systematic way of characterizing the dynamic network of S&T-related institutions, actors, government policies and practices that make up a country's overall S&T capabilities. In other words, it is what enables a nation to make scientific discoveries, to advance knowledge, and innovate technologically, producing novel products.

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A national innovation system is typically made up of educational and training institutions such as universities, R&D organizations, government policies supporting S&T development, regulations that protect the products of high-tech R&D (such as patent systems and intellectual property rights laws), and financial resources for funding R&D (including government funds, venture capital or foreign direct investments). The knowledge- and people-flow between these institutions are what enable innovation and learning to take place.

In order to become a part of the 21st century knowledge and information revolution, China has continued moving away from a natural resource-intensive economy into broad-based, knowledge-intensive industries and services. This has required updating the economic, institutional and regulatory regime to nurture basic, applied and commercializable R&D, strengthening their educational facilities, building the requisite information infrastructure to support a knowledge economy, and continuing to exploit existing global S&T knowledge from the outside. Acquiring knowledge from foreign companies—either by training, joint ventures, reverse engineering existing products, or ignoring intellectual property rights—has been a highly effective way for many Asian tigers, such as Japan and Taiwan, to build up their high-tech know-how.

China's current rapid economic growth, due primarily to the shifting of workers and resources from low productivity agriculture to industry, and to very high rates of domestic and foreign investment, has aided these efforts greatly. Maintaining current growth rates will be difficult, however, given the burden of inefficient state-owned enterprises and a large portfolio of non performing loans.

Geographical disparities remain significant. The country's fastest industrial growth has been concentrated in coastal regions, which are the most open to international trade and receive the greatest share of foreign direct investment. The highly developed cities of the coast are home to dynamic businesses, industrial parks similar to those in South Korea or Taiwan, and massive tracts of new office buildings and infrastructure (such as superhighways, public transport systems, municipal water and sewage plants, power grids, and advanced information networks).

Not that far away, in central and western China, poverty is still prevalent, and educational, public health, and information infrastructure remain in poor condition. To overcome inadequate access to capital, education, and other assets in these areas, regional governments have engaged in a campaign to encourage new domestic and foreign investment. In part, as a consequence of such efforts, IBM, Intel, Hewlett-Packard, Time Warner, Coca Cola, and other foreign companies opened businesses in the central and western provinces, where labor and start-up costs are cheaper.

China's current industrial base is a much more integrated system than the stovepipes and strict division of labor that existed prior to the country's opening-up. This has enabled a greater number and variety of players to become engaged in building technological capacity. However, significant weaknesses exist: poorly developed formal and informal information networks; corruption and lack of accounting transparency; uneven application of industrial standards and quality control; lack of respect for intellectual property rights; excessive government control of the detailed management of S&T research institutions; and scarce venture capital.

Currently over 60% of the country's R&D is carried out in industry. This work is still primarily low-and middle-end technology, involving mostly re-engineering of foreign technologies or creative duplication of their designs. China remains in transition: despite being such a large and diverse country, the majority of Chinese firms are still not at the level where they can truly innovate. There have been a few exceptions, however, such as new Chinese 3rd generation telecom wireless standards and a Chinese language word-processing technology.

In terms of strategy, China has not followed the Korean national innovation system model of developing big high tech corporations (*chaebols*) with known brand names such as Daewo or Hyundai. Instead, it has steered more towards the model of Taiwan, which achieved more as an original equipment supplier to foreign companies than it did by developing its own brand names. In fact, Chinese companies could be considered hybrids—a mix of foreign technology and managers with raw domestic talent.

BACK TO BASICS: THE UNIVERSITY SYSTEM AFTER THE MAJOR EXPANSION

University education in China has become much more widespread since the Cultural Revolution, which prevented a generation of Chinese from completing their education. Considering that China's first PhD was granted in 1983, the higher educational system has made phenomenal progress in a short time period. Particularly since 1999, college admission achieved double-digit growth consecutively for the next few years, raising total enrollment (excluding adult higher education services) in universities from 3.41 million in 1998 to 7.19 million in 2001, and to 13.34 million in 2004. The gross enrollment rate in China has reached 22% by 2006, compared to 5% in the early 1990s. Almost half of Chinese undergraduates major in science or engineering. Like the U.S., China is one of the few countries where doctoral students must continue to take courses, rather than going directly to thesis work as many EU countries, implying greater rigor in their degrees.

The challenge of teaching independent thought and creativity has been complicated by several factors, including a legacy of centuries of Confucian philosophy, which places a priority on respect for authority and seniority; years of central planning in the economy; and widespread rote-learning, long considered the best approach for preparing students for national college entrance exams. To address this challenge, and focus students on practical questions, Chinese universities have been trying to develop close ties to industry. Curricula may emphasize commercial interests in order to better prepare students for a career as competition grows for good jobs.

China has over 1000 institutions of higher learning, although few outside the top 30 get much recognition. Top universities—Beida, Tsinghua, Fudan, Zhejiang, Nanjing, Shanghai Jiaotong, Xian Jiaotong, Harbin Institute of Technology, among others—get most of the research money from government and industry. Chinese universities are not funded exclusively by the government, so they have to develop alternative sources of funding (which include the generation of high-tech spin-offs). Most graduate education is free; reformers are urging the government to charge tuition for graduate school and introduce a system of research or teaching fellowships as in the U.S.. The few private universities specialize in business, management, and similar disciplines, and typically offer only the equivalent of an associate degree.

The most prestigious universities in science and engineering are Tsinghua University, Zhejiang University, Shanghai Jiaotong University, and a few others. Many of their faculty are quite accomplished, however, in order to maintain their reputations they are pressed to produce research results, publish, travel to give talks, and obtain patents on their inventions, leaving them little time to teach.

Lately, the government has sought to improve the quality of less well-known universities, especially in the poorest areas of the country, through a focused support program based on specialized disciplines. Other needed educations reforms include integrating the private higher education system into the official system; enabling poor but talented students to attend college; revamping vocational training to make it more responsive to industry needs; providing retraining programs for displaced workers; and continuing to develop distance learning and adult education.

IN SEARCH OF DIRECTIONS: RESEARCH INSTITUTES AFTER "ZHUANZHI"

Basic Science Research

China is not yet a world leader in basic science, despite sustained government efforts in recent years. China's investments in basic research has increased by a factor of almost 6.5 between 1991 and 2001, a 17 percent average increase per year, reaching the level of $84.6 billion USD in the year 2003.[1] But both total investment in basic research and investment per researcher are lower than in developed countries. Indeed, basic research spending as the percentage of the total research and development (R&D) expenditures actually decreased from 7.5 percent in the 1990s to its current level of 6 percent in 2002. There are currently 957,000 people engaged in R&D in China, 79,000 of them in basic research, so the percentage of basic research scientists to the total R&D personnel is 8.3 percent.

The most important institutions conducting basic research in China are the research institutes of the Chinese Academy of Sciences. During the early stages of China's economic reform, funding was cut for many Chinese Academy of Sciences' and other research institutes. This pushed the institutes to seek funding from industry. In 1998, the Chinese Academy of Sciences succeeded in persuading the government to provide concentrated support for both basic and strategic research at the Academy through a "knowledge innovation" program. Subsequently, many Chinese Academy of Sciences institutes consolidated their research areas and established new ones to better attract overseas Chinese students.[2]

In terms of quantity, the volume of Chinese basic research has clearly increased, as is evident from the rise in China's ranking in terms of papers published in international journals. China's contribution to world scientific publications rose to 6.5% of the world total in 2004, compared with 2% in 1995; the 2004 figure ranked China 5th after the U.S., Japan, the U.K., and Germany. In specific research fields, China's progress is even more significant. For example, China ranked third in publications in nanotechnology, following only the U.S. and Japan. Yet despite rapid growth in the number of papers published, quality indicators of these publications in general have not measured up to those of developed countries. For example, Sir David King, The Chief Scientist of the U.K., ranked China in 19th position, based on its share of the most highly cited publications between 1993 and 2001.[3] A study by Leydesdorff and Zhou similarly found that citation rates for papers published by Chinese scholars are relatively low.[4] The take-away is that China still does not have enough world-class scientists to support its aspirations.

Brain drain has been a problem in China since the early 1900's when China began sending its best and brightest students abroad to study. In the last few decades, many of these students have not been returning; the U.S. has been a favorite place for many of them to stay. From 1988-1996, of the over 43,000 Chinese students receiving U.S. doctoral degrees in science and engineering, roughly 48% of them had firm plans to stay abroad. As a consequence, China has implemented a variety programs at different levels to lure back home U.S.- and EU- trained Chinese students, as well as top-ranked U.S. Chinese-American scientists and engineers. The lure of booming high tech industries in China, higher wages, incentives offered by companies, and better living conditions entice some to return. These returnees bring with them the benefits of S&T knowledge and know-how from more advanced countries like the U.S. China's capacity to harness this momentum and make large strides in developing their technological capabilities, especially in the information technology sector, should not be underestimated.

Government S&T Policies and Programs

Government policies have had a profound effect on China's ability to transform itself into a knowledge economy and build a science and technology industrial base, with reforms dating back to the mid-1980s when policies focused on orienting the S&T system towards economic growth and increased investment in S&T and education (they aimed at making each 1.5% and 4% of GDP respectively by the year 2000, a goal not reached; in 2002, R&D as share of GDP was 1.22).[5] This strategy has had the full support of Chinese leadership.

China's original Soviet-style, centrally-planned governmental system for S&T, dating from the 1950's, was rigid, overly-bureaucratic and hierarchical, though still with good administrative control. The system indulged far too much in long-term central planning and stymied efforts to develop and modernize S&T in China. The system was, however, able to mobilize some Chinese S&T resources to bolster its military technology, for example in nuclear weapons and ballistic missile technology, along with help from the Soviets—although this required an enormous amount of effort and coordination.

The shift in relations with the Soviets in the 1960's, together with the political, economic and social upheavals during the Cultural Revolution greatly stifled the development of S&T in China. During this period universities were closed and the intelligentsia was silenced, banished or imprisoned, resulting today in a lost generation of academics, educated professionals and intellectual talent.

This was followed by Deng Xiaoping's "Open Door" policies, which brought increased foreign trade and market-oriented economic reforms, and greater absorption of S&T from the West, opening the way for some foreign companies to enter the country. The government realized that research must be tied to the commercial sector, and become more market-oriented, technology-based and focused on industrial development.

The latest government policies formulated at the National Conference on Science and Technology in Beijing in 1995, the *kejiao xingguo* (Reinvigorating China through Science and Education) strategy, set the direction for S&T for the next ten years to twenty years. Under this effort, Chinese Premier Li Peng founded the State Leading Group for Science, Technology and Education, composed of the chiefs of the leading S&T, education, and economic agencies, in addition to himself and the Vice-Premier. The Group has the responsibility for coordinating and evaluating the nation's overall strategy for S&T and educational development and is often briefed by leading scientists, particularly to inform them on "hot topics" such as nanotechnology, electronics, software, e-government, biomedical, and environmental technologies.

Currently, the most important governmental organizations in science and technology research are the Ministry of Science and Technology (MOST), the National Natural Science Foundation of China, the Chinese Academy of

Sciences and the Chinese Academy of Engineering. Along with MOST, the Commission on Science and Technology and Industry for National Defense, and the Ministry of Education have policy-making authority; the Chinese Academy of Sciences (which also administrates about 100 national research institutes, mostly in basic science) and Chinese Academy of Engineering have advisory power; and National Natural Science Foundation of China provides research funds.

MOST is responsible for the nation's civilian S&T activities, devising programs and policies for strengthening the S&T base in the private and public sector; for continuing systemic reforms, and for administration of China's high tech industrial development zones. In recent years, most of its activities have focused on developing S&T strategies, particularly in high tech, to accelerate economic growth.

The National Natural Science Foundation of China (NSFC), founded in 1996, modeled very closely on the U.S. National Science Foundation (NSF) model, funds basic research activities, although, unlike NSF, only in the natural sciences. They do this by soliciting research proposals and awarding grants based on peer review. Competition is strong—only about one in seven research proposals are successful. The NSFC received $425 million in government funding in 2005, a 25% increase over the previous year. By 2010 the NSFC's budget is expected to double to reach $850 million. Life sciences usually receive the most funding, followed by engineering and materials science, mathematics and physical sciences, and management science.

How successful have these government policies been? Despite its single-mindedness, and the injection of huge amounts of money into research and S&T personnel, the country did not reach its goal of making R&D 1.5% and educational spending 4% of GDP by 2002. There are still lacunae in the country's national innovation system, especially the weak industrial R&D capabilities and the fragile linkages among different players in the national innovation system, which serve as vital channels for technology transfer among sectors, and help build up knowledge capital. Further, some say there are too many bureaucratic fiefdoms dispensing scarce resources based on self-interest. Coupled with turf battles, the result may be ineffective R&D spending. Scientific personnel (2 million scientists and engineers in 2000), is unevenly distributed, with the best in academia rather than industry. Most senior positions are dominated by older scientists, most of whom are soon to retire.

High tech exports are still mostly from multinational corporations, and are low and middle-end rather than high end products, indicating an inability to truly take intellectual risks and innovate. There may also have been a decline in first-class achievements: from 1989-2001, there were no winners of first class prize in China's biennial Natural Science Award.

Nonetheless, China has already traversed a long, uphill road to scientific achievement, and the concrete knowledge and experience gained will undoubtedly aid the country in scaling even greater heights. The government's single minded commitment to building its S&T capabilities, sustained for over three decades, continues to be strong, with R&D expenditures averaging over 25% growth per year in the last five years. There is now a vibrant and growing industrial community, with a variety of types of enterprises other than state-owned—township and village, joint-venture, private, and foreign—that did not exist before the reforms. These enterprises are beginning to compete and cooperate, and this new industrial pluralism will help promote the exchange of ideas and S&T overall in the industrial sector.

A TALE OF TWO CITIES: INNOVATION IN DOMESTIC FIRMS AND MULTINATIONAL CORPORATIONS

China's efforts to build a domestic technology capacity began by using public research institutes and state-owned enterprises as their main vehicles. However, state-owned enterprises were still part of the centralized bureaucracy and too encumbered by rules, too controlled and bureaucratic, and too disconnected from market forces to be successful. By 1995, realizing their failure to make state-owned enterprises the agents of change for high tech development, the government declared that the marketplace, rather than government control, would be the predominant force in developing technological capabilities. While some state-owned enterprises recently have turned around and become profitable, overall the massive debt state-owned enterprises have accumulated continues to be a financial burden for the government.

The number of privately-owned companies in China has grown quickly over the last few decades, although with great variance over different regions and industries. Private firms have boomed in coastal regions of the country, such as Zhejiang, Jiangsu and Guangdong provinces—the most successful industries being information and communications technology. Indigenous companies benefit from knowledge of the local market, preferential treatment by the government (such as tax waivers, land deals, contracts and financial incentives), and the low costs of producing, marketing and selling their product.

Most indigenous R&D primarily consists of reverse engineering or slightly modifying older generation foreign technologies, such as legacy wireless devices or communications switching devices. However some domestic Chinese companies have emerged as true innovators in selected industries, such as the Founder Group, a 1986 spin-off from Beijing University and now a leading producer of Chinese digital language printing systems, and Huawei, a leading player in the global telecom market with R&D centers in Silicon Valley and Dallas, TX.

In terms of quality control and strict adherence to standards—either international, such as ISO 9000, or domestic—the record is spotty. Yet, for particular firms, meeting such standards is essential in order to compete successfully in global manufacturing markets. It is likely that within 10 years a significant number of Chinese companies will have successfully implemented international standards.

China has been the world's biggest exporter of information technologies (or information and communications technology, "ICT," as it is frequently termed in EU countries) products since 2004, accounting for about $180 billion and 30% of all of China's exports in 2005. Most has been computer and related equipment used to assemble computer, audio, video and telecommunications equipment; China still has to import most high value electronic components needed for ICT manufacture. Domestic demand is strong for these products, so industry growth has averaged a dramatic 27-30% a year. Their present level of success is due to demand, foreign direct investment and government's role in driving the industry forward in the last 15 years.

Most Chinese ICT firms are small in term of revenues and employees—only China Telecom ranks in the world's top 250 ICT companies. The main challenges facing this industry center on building management skills, innovative capabilities, global brands and reducing over dependency on foreign companies for core technologies, although joint ventures with U.S. firms like Motorola, IBM, Intel, Hewlett-Packard, Compaq and Dell have improved domestic production capabilities and technology absorption. In software, China still lags way behind more developed countries, despite having over 6000 software companies in 2002 and a firm commitment from the Chinese government to foster industry growth. High domestic demand, a growing local skill base and greater intellectual property protection will facilitate this trend.

As the world's largest telecommunications market by subscriber base, China has emerged as a significant player in the global telecom industry, both as supplier and buyer. In 2005, of every 100 households, about 111 had cell phones in urban environments and over 24 in rural; there were about 33 PCs (urban) and almost 2 (rural). In the same year, there were about 111 million Internet users, and a high penetration of television and cable TV. All these devices require an extensive information infrastructure in order to function. Since the country first encouraged telecom multinational corporations to come to China, much of the technology for this sector has been absorbed from the outside, however the landscape is rapidly changing due to the improved production and export capacity of domestic firms. For example, three major Chinese telecom firms, Huawei, ZTE Corp. and TCL almost doubled their annual revenues from 2000 to 2005, reaching $5.9B, $2.7B and $4.4B respectively.

Most indigenous telecom manufacturers spend about 10% of revenues on

R&D and many have links to China's universities or governmental basic research facilities. Now that 3rd generation wireless technologies have started to be used worldwide, companies such as Huawei are considered to be at roughly the same level as global competitors, having shortened their learning curve over time. In fact, China has developed its own third generation wireless telecom standard, called TD-SCDMA, which is now considered as one of the three official world standards for wireless technologies.

In addition to R&D, many foreign companies are investing in manufacturing in China, given the low cost labor and huge highly skilled and disciplined work force. Most is still not terribly advanced in design or sophistication. This requires high tech equipment which is highly automated and optimized, modern management techniques and systems integration skills which are only now starting to be seen in China.

Multinational corporations

Many U.S. and foreign multinational corporations have been involved in Chinese markets since the early to mid-1980's, primarily with low-end manufacturing activities. However, with China's World Trade Organization membership, more companies are securing a higher position in value-added production chains and have built their own R&D centers in China. The official government figure puts it at 750, with the most recent estimate reaching as high as over 900.[6] Most of these centers are located in Beijing and Shanghai to take full advantage of regional government incentives. Many are close to the major universities or research institutes. Over half are in the ICT sector.

Most of the activity in these R&D centers is more "D" than "R", yet it is still a big step up from low-end assembly of high tech components. Most of the important U.S. multinational corporations, such as Motorola, Google, IBM, Nortel, Lucent, Microsoft, Oracle and others have research centers in China, as well as Alcatel (France), Ericsson (Sweden) and Infosys (India). Most higher level employees are recruited from top Chinese universities and trained in U.S. engineering and managerial tasks. In addition to R&D, these centers also carry out other forms of knowledge transfer such as education and training programs, technology licensing agreements, contract research with local university researchers and equipment donations. Experts claim that it is hard to judge whether these MNC R&D centers have been successful due to lack of reliable indicators.

Intellectual Property Rights

The Chinese patent system was established in 1984, as part of the economic and legal reform effort. Government's objective was to create an environment conducive to foreign investment and technology transfer, as well as stimulate Chinese scientists and engineers to innovate. The current system is modeled on those of developing countries, and conforms to most international norms for patent protection, such as those embodied in the Agreement on Trade-Related Intellectual Property Rights (TRIPS).

There are still major problems with enforcement, piracy and counterfeiting; a 2003 report by the China State Council's Development Research Center put the market value of counterfeit goods in China between $19-24 billion from infringement of patent rights, copyright, trademarks and other property rights. Many U.S. companies complain that police are either not interested in pursuing intellectual property rights infringement, or lack the training and resources. Other factors that discourage intellectual property rights enforcement include lack of coordination among government ministries and agencies, corruption and regional protectionism.

That said, "acquiring" ideas from abroad has historically been a highly effective means for newly industrializing countries to build their S&T capabilities. For example, American colonial entrepreneurs learned as many trade secrets as they could from visiting British textile mills in the early 19th century in order to establish the industry in their own country.

To address these problems in China, the U.S. government has recommended measures such as lower thresholds for prosecution or higher penalties. The Chinese government is displaying a greater willingness to prosecute, with more resources to support enforcement and more coordination among the various entities involved in intellectual property rights.

Though a well-functioning patent system would clearly help to encourage more foreign high tech involvement in China, the idea of a legal system to protect intellectual property runs counter to several important traditions in China. One is a Confucian tradition indicating that inventions or creations belonged to all members of society by definition and also Socialist ideals don't adhere to the idea of private property.

China has been a member of the World Trade Organization for only a few years, after 15 years of negotiations, and as such, is committed to implementing wide reforms in areas such as intellectual property rights, limiting preferential treatment of domestic companies, general transparency in business and trade, and other changes to bring its legal and regulatory system in line with those of other World Trade Organization members. In addition, as more Chinese patent their own products, they will have a vested interest in protecting their own intellectual property rights.

FUTURE PROSPECTS

China has experienced incredible economic growth and buildup of its technological capabilities in the last three decades. Barring unforeseen disasters, it will no doubt continue on this upward trajectory. The Chinese national innovation system has also made enormous strides in the last three decades and shows no sign of

Ingredients for NIS Success?

Richard Nelson (2004) identifies several elements involved in building up a successful National Innovation System that were shared by the “Asian Miracle” countries, such as South Korea, Taiwan or Singapore. These may help shed light on China’s current technological trajectory. The elements are:

- Transborder flows of people, with people from industrializing countries going abroad to learn and then returning, and people from advanced countries coming in as advisors or to establish businesses in the host country.
- Active government support in technological catch-up activities, by offering subsidies to fledgling domestic firms, government encouragement of entrepreneurship and other forms of protection.
- Poor enforcement of IPR regimes at early stages of the catch-up process, so as not to hamper the industrializing country in copying or imitating mature foreign technologies.
- Governments with outward-looking, export-led industrial policies.
- Firms that gradually learn technological capabilities via a difficult trial and error experimental process, involving investments in training and slowly moving from simple assembly of technology to slight design modification to more complex tasks and eventual R&D.

Nelson, R.R., “The Challenge of Building Effective Innovation Systems for Catch-up”, *Oxford Development Studies*, Vol. 32, No. 3, September 2004, pp. 365-374.

slowing down—as long as foreign direct investment continues to flow, and with it technology and knowledge acquisition opportunities. Government reform in S&T continues, with increasing amounts of money going into R&D on a national scale. In terms of percent of GDP spent on R&D, China has made important progress in the last few years, reaching at 1.4% in 2006. Japan spends currently about 3.1% (2002) and the U.S. about 2.7%. The U.S. number is expected to remain flat for some time. The *Wall Street Journal* has stated that if Chinese R&D spending can reach 2% of GDP by 2010, given their massive yearly production of science and engineering graduates (over 57% of undergraduate degrees in 2002), it will make them a veritable global S&T powerhouse.

As China’s national innovation system evolves, it will continue to absorb knowledge, basic science and engineering know-how, technical and corporate management skills, design and production techniques, and sales and marketing savvy—largely by trial and error. These will serve to grow the system organically, conforming to international trends and best practices as well as to domestic realities—given China’s intrinsic strengths and weaknesses, unique cultural characteristics and legacies from the past. China’s government has made it clear that, policy-wise, S&T will continue to be a fundamental priority and driver for economic growth, allowing both quantity and quality of innovation to improve. It is also likely that in selected areas such as nanotechnology, biotechnology and information technology, China will become one of the major research clusters in the world.

There are still obstacles in the upward path of China's national innovation system. Perhaps the most significant come from macroeconomic and social challenges that now confront the Chinese leadership. Notable examples include the growing disparities between rural and urban areas, and among different regions; the financial burden of many thousands of non-performing loans to the state-owned enterprises; corruption and inefficiency in the government; lack of jobs for millions migrating from the country to the large cities; social unrest; a weak legal regime underlying commercial activities and intellectual property rights; and wide-spread environmental problems.

Support and help from the global S&T community will ... aid China in becoming more integrated in the global knowledge economy, and will work against internal sentiments of "techno-nationalism" and external views of the country as newly emerging high-tech threat.

Within China's national innovation system itself there are problems which must be surmounted: first of all, China's industrial R&D capabilities are still relatively weak, relying mostly on low cost labor as their major competitive advantage. Cultivating these capabilities is the most important task of the system. Second, the weak linkages among industry, research institutes, and universities have also prevented knowledge from being created and efficiently diffused among sectors. Chinese universities and research institutes have had some interesting history in establishing close ties with the market by running spin-off companies themselves over the last two decades. However, in recent years, scandals and corruption in these companies have fostered doubts about the viability of this model as an effective mode of "technology transfer." In addition, many Chinese national research institutes have to struggle to define their roles in China's national innovation system after many of their peers have been pushed to join the market as full-fledged, for-profit companies, or self-sufficient NGOs.

It may be that the invisible hand of the market will resolve these issues over time, although that is doubtful. Support and help from the global S&T community will have to play a major role. This will aid China in becoming more integrated into the global knowledge economy, and will work against internal sentiments of "techno-nationalism" and external views of the country as a newly emerging high-tech threat. A stronger Chinese national innovation system will in turn serve the rest of the world by expanding and exploiting the global market for foreign goods and services, and by opening up new investment avenues for high tech companies and multinationals. As much of the industrial R&D carried on at present in China is for multinational corporations, the intellectual property is channeled back to the host country in one way or another.

The new global geography of science and technology is not a zero-sum game. Instead of becoming a major technological superpower in head-to-head competition with the U.S., Japan, and Europe, China will ultimately join others in a shared leadership role. As China continues to develop, we expect that it will fully integrate into, but in no way come to dominate, the global innovation system and related business value chains. Such a relationship with the world S&T community will enable flows of knowledge, commerce, and people that sustain China's development, while permitting the country to make its own very unique contribution to the advancement of knowledge and technological innovation on a global scale.

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

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1. In purchasing-power-parity (PPP) dollars, according to *OECD, Main Science, Technology and Industry Scoreboard: 2005* pg. 21.
2. See Peter Suttemeir and Cao Cong (2006). "Chinese Academy of Sciences (CAS) Knowledge Innovation Program," *Physics Today* 39 (December); see also a paper by the same authors with Denis Simon in the previous issue of this journal.
3. David A. King (2004). "The Scientific Impact of Nations," *Nature* 430 (15 July), pp. 311-316. See also Wilsdon, James, and James Keeley (2007). "China: the Next Science Superpower?," *Demos* January 2007. <http://www.demos.co.U.K./files/China_Final.pdf> last accessed 3/7/07.
4. Leydesdorff, L., and Zhou, Ping (2005). "Are the contributions of China and Korea upsetting the world system of science?" *Scientometrics*, 63, No.3.
5. National Science Foundation (2006) *NSF Science and Engineering Indicators*: *2006*, pp. 4-45.
6. Presentation given by Prof. Dennis Simon of State University of New York at a conference organized by DEMOS in London in January, 2007.