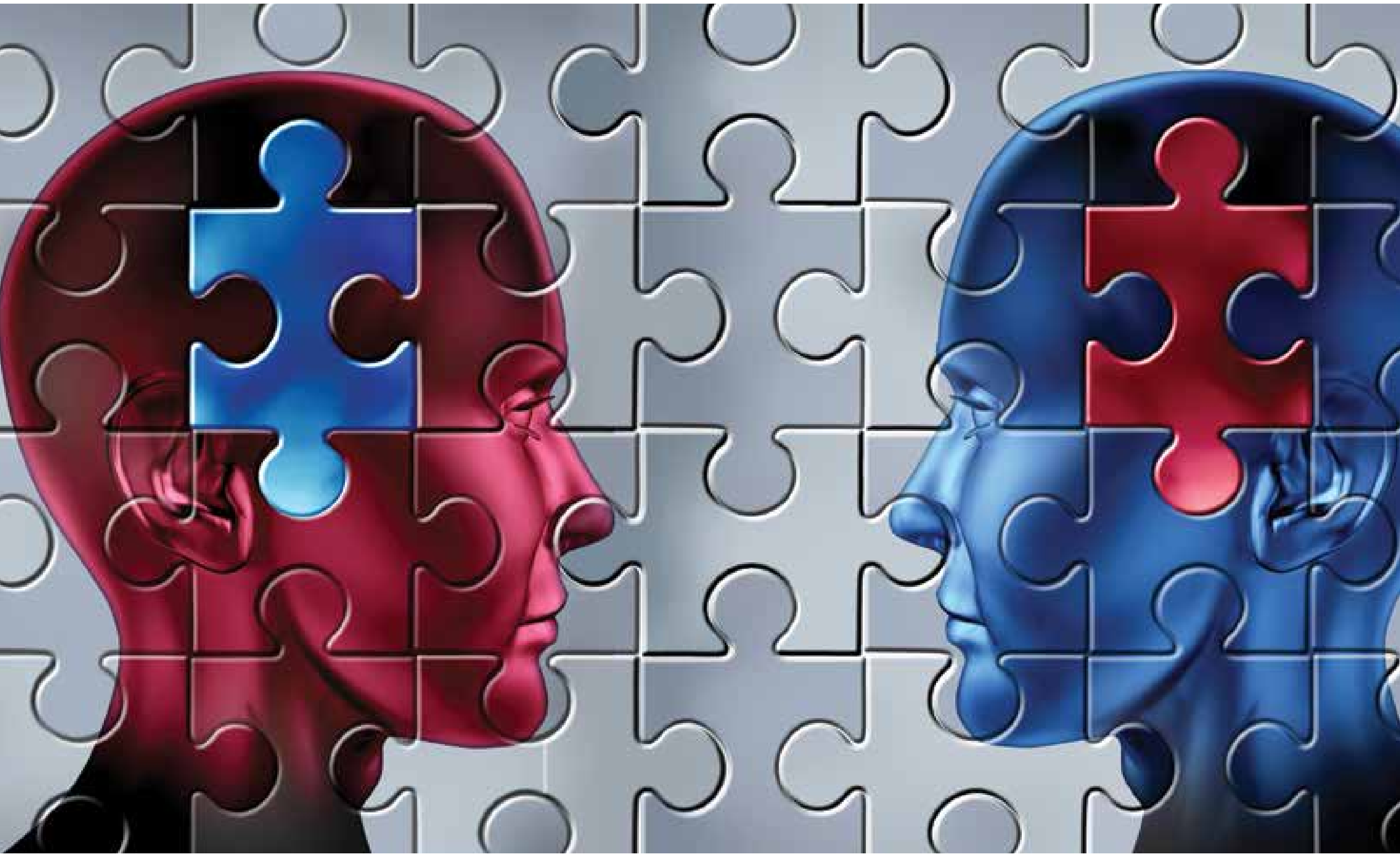

CHAPTER 12

U.S.-CHINA SCIENCE AND TECHNOLOGY COOPERATION

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Executive Summary

Since the second half of the 20th century, global science and technology (S&T) have advanced by leaps and bounds. The U.S. – with its strong foundation of support for S&T development, research and development (R&D) activities, manufacturing capabilities and its comprehensive national talent pool – has been at the forefront of the world's technological revolution, from microelectronics and IT to life sciences and clean energy. China, as an ancient, oriental civilization, has tried to leverage its huge domestic market and strong statist orientation to catch up with the developed countries over the past 30 years. Propelled by Deng Xiaoping's program of economic reform and opening up policy, this effort has gathered increasing momentum and has yielded significant results. The U.S. and China have independently developed their own unique paths in the field of S&T policy and innovation strategy, using their array of competitive advantages and national assets. The interface between the 'high-technology' orientation of the U.S. and China's 'large domestic market' has served as an attractive value proposition for the growth of U.S.-China cooperation across a wide range of scientific fields and industrial sectors.

Starting with the establishment of diplomatic relations between the U.S. and China in 1979, the two nations have witnessed many important achievements in such key fields as energy, agricultural S&T, and wireless communications technology. Looking into the future, based on the evolving patterns of S&T development in both countries, it seems clear that the two nations have many potential opportunities for deepening as well as expanding their bilateral cooperation and collaboration. Moreover, with ample consultation and coordination, the two nations could form a truly unique strategic win-win partnership: American companies operating in China could further enhance the rate of return on their investments, while China could continue to energize its S&T development and accelerate its industrial upgrading. More importantly, enhanced S&T cooperation between the two nations could help both countries reach a useful consensus on a series of critical global issues including renewable energy, food security, climate change and healthcare – thus fostering a more positive sum, collaborative approach to international agenda setting. Clearly, there continue to be many problems and hurdles that plague U.S.-China S&T cooperation, including disputes over intellectual property rights, export control restrictions, trade barriers and most recently, information security. Amelioration of these problems will require nothing less than continuous bilateral engagement, negotiation and dialogue at the highest levels of both governments.

The content of this paper begins with an analysis of the development, priorities and trends in U.S. and China S&T affairs as well as the core S&T strengths of the two nations. The paper then examines the prospects for possible future cooperation, highlighting some of the successes of the past 30 years of S&T cooperation, including a case study in the field of energy. The paper also explores areas of friction and tension in the S&T cooperation process and ends with a series of policy proposals for removing existing barriers and areas of disagreement.

U.S.-China Science and Technology Cooperation

U.S.-China S&T Development: Status and Trends

The overall state of American S&T development

Since the end of World War II (WWII), the U.S. has been the worldwide leader in S&T, whether measured in terms of scientific and engineering personnel, R&D funding and performance, etc. The U.S. has played a demonstrable role in shaping the thrust and direction of global S&T development. Generally speaking, throughout this period, the U.S. has continued to invest steadily in both R&D and manufacturing advancement – despite most recently facing a serious downturn in the global economy and high government deficits. According to the *United Nations Educational, Scientific and Cultural Organization* (UNESCO) *Science Report 2010: The Current Status of Science around the World*, the U.S. not only remains the world's leader in terms of R&D investment and scientific research achievements, but it also remains far ahead of most other countries and economies. U.S. President Barack Obama's administration has indicated its intention to increase the country's R&D expenditure as a percentage of gross domestic product (GDP) from 2.7% to 3%, especially in the fields of clean energy R&D[1, 2]. To further spur on and guarantee continued American technological leadership, the U.S. government announced the following specific measures:

Promote U.S. manufacturing and enhance overall competitiveness
According to the "Advanced Manufacturing Partnership" announced by the U.S. government in 2011, federal funding will reach US$2.2bn for manufacturing sector R&D at the National Institute of Standards and Technology, Department of Energy and the National Science Foundation.

Develop a clean energy economy and create employment for the future
Clean energy is considered to be one of the core industries underlying U.S. leadership in global S&T affairs. Therefore, it is not surprising that it has been given vigorous support by the American government[3]. The designated budget for 2013 was over US$90bn. While very optimistic, the U.S. plans to increase its clean energy generating capacity from the current level of approximately 40% to 80% by 2035; it will also increase basic research in a broad range of fields related to clean energy, including solar energy, wind power, environmental protection, transportation, biochemical products, etc.

Train the next generation of S&T leaders, including training 100,000 S&T teachers for the next decade
To enhance the U.S.' future competitiveness, cultivating ample S&T talent is viewed, by far, as the most important factor and determinant of success. The government plans to educate 100,000 teachers in science, technology, engineering and mathematics (STEM) fields for K-12 (primary and secondary)

1 *UNESCO Science Report 2010: The Current Status of Science around the World*, United Nations Educational, Scientific and Cultural Organization, Paris, 2010.
2 The White House Document "Supporting American Innovation", http://www.whitehouse.gov/omb/factsheet/supporting-american-innovation
3 The White House Document, "Creating the Clean Energy of Tomorrow and Protecting the Environment and Natural Resources", http://www.whitehouse.gov/sites/default/files/microsites/ostp/fy2013omb_ee.pdf

education[4]. Meanwhile, the U.S. is amending its immigration laws to attract and retain more high-tech talent; it is hoping to attract more foreign students with degrees in key S&T fields to remain in the U.S. after they complete their studies, especially at the graduate level.

Continue to increase investment in basic research, create a full-scale technical transformation and develop the jobs of the future

Since the end of WWII, the U.S. has stood in the forefront of technology advances and R&D investment in the world. According to the U.S. Government Accountability Office (GAO) data, the government was projected to invest US$142.2bn in R&D in 2013, about half going to defense research and the rest to support core research institutions, including National Institutes of Health (NIH), National Science Foundation, Department of Energy and National Institute of Standards and Technology. The government has proposed a series of policies and initiatives to bring about a comprehensive transformation of the U.S. technological base, further develop the domestic job market and mobilize a full plethora of resources to support advances in clean energy, wireless communication technology and advanced manufacturing – leading to the overall upgrade of America's industrial foundation and the development of a broad range of new job opportunities. Unfortunately, however, due to the problem of the U.S. budget deficit and its associated impact on available funding to support these stated goals, enactment of President Obama's current and future budgets remain highly uncertain.

Support the biomedical industry

The biomedical industry is known as a 'sunrise industry' and is seen as one of the leading sectors for driving the global economy in the 21st century. The U.S. effort in this area is designed to ensure continued American leadership in this strategically important field. The U.S. government is expected to allocate approximately US$31bn to NIH for basic and applied biomedical research[5]. Biomedical research has the potential to:

- Create new, large-scale employment opportunities;
- The birth of new technologies will help drive enterprises onto a road of sustainable development in this field, bringing more new products to the market and opening up more diversified types of employment for the community;
- Create positive interactions among policymakers, researchers and commercial enterprises; and
- Promote the future onset of the widely coveted new knowledge economy.

Support efforts to increase wireless communications and IT

Wireless communications and IT are widely used in military, commercial and daily life. U.S. leadership in global commercial and economic affairs cannot be separated from its stable, efficient wireless communications technology. The U.S. government initiated the "National Wireless Initiative"[6], to encourage R&D of a new generation of wireless communications technology products, including smartphones, tablet PCs, and innovative hardware and software products and services. Currently, there has been more than US$10bn invested in the so-called "Wireless Technology Innovation Fund" to promote development and application of new, cutting-edge technologies. Developments associated with these funds will play a critical role in U.S.

4 The White House Document, "Preparing a 21st Century Workforce",http://www.whitehouse.gov/sites/default/files/microsites/ostp/fy2013rd_stem.pdf

5 The White House Document "Supporting American Innovation", http://www.whitehouse.gov/omb/factsheet/supporting-american-innovation

6 The White House Document, "President Obama Details Plan to Win the Future through Expanded Wireless Access", http://www.whitehouse.gov/the-press-office/2011/02/10/president-obama-details-plan-win-future-through-expanded-wireless-access; The White House Document, "Remarks by the President on the National Wireless Initiative in Marquette, Michigan", http://www.whitehouse.gov/the-press-office/2011/02/10/remarks-president-national-wireless-initiative-marquette-michigan

economic development in the future – ideally creating many new forms of employment and helping to facilitate the onset of a more efficient and effective networked society.

Become a world leader in nanotechnology and related types of new materials[7]

The U.S. has made an explicit commitment to strengthen ongoing efforts regarding the commercialization of nanotechnology. The key measures include:

- Extending the R& D chain and accelerating large-scale production;
- Addressing the concerns and needs of industry, and speeding up the commercialization process;
- Strengthening infrastructure construction, establishing national equipment suppliers and related support systems;
- Supporting nanotechnology-related small businesses; and
- Enhancing U.S. participation in the field of nanotechnology internationally[8].

Ensure that U.S. military industrial technology continues to be the worldwide leader

Investment in R&D and production equipment for generating advanced military technology is an integral part of the national S&T and innovation infrastructure. America's large military production network supports the global projection of U.S. armed forces along with the development of sophisticated weapons and associated improvements. The military S&T system is also tied to a multiplicity of civilian innovation thrusts, including the high-speed network of satellite technology that serves both defense and non-defense constituencies[9].

7 The White House Document, "The NNI Vision and Strategic Plan", http://www.whitehouse.gov/administration/eop/ostp/NNIStrategy
8 *National Nanotechnology Initiative Strategic Plan*, National Science and Technology Council, 2011.
9 The White House Document "Supporting American Innovation", http://www.whitehouse.gov/omb/factsheet/supporting-american-innovation.

The current status and direction of China's S&T development

In recent years, the continued growth of Chinese government investment in S&T as well as its initiation of a wide range of new policies to support the strengthening of domestic innovation capacity has attracted worldwide attention. Over the past decade, China's R&D intensity has increased quite rapidly, with R&D spending expanding at an annual rate of 20% or more. China has become a major force in promoting the growth of R&D spending among all the nations in the Asia region. It is estimated that in 2012, China's R&D investment reached approximately RMB 1.0 trillion, with R&D expenditures as a share of GDP climbing to 1.83%, thus placing China in the same range of many moderately developed countries[10]. China's output of cited S&T papers in refereed journals and the number of new patent applications have also been growing very rapidly. In addition, the Chinese government has introduced a series of new programs and policy measures to enable Chinese S&T to achieve leapfrog developments in a variety of key fields.

"15-Year National Long-to-Medium-Term Science and Technology Development Plan"

In 2006, the Chinese government issued the "15-Year National Long-to-Medium-Term Science and Technology Development Plan (2006-2020)" (MLP), which represented the first comprehensive national S&T plan since the establishment of China's market-oriented economic system and People's Republic of China's (P.R.C.'s) accession to the World Trade Organization. The MLP articulated a strategic blueprint for China's S&T development over the next 15 years. The plan, which remains in place today, provides guidelines for S&T work up to 2020; it encourages a greater emphasis on indigenous in-

10 Juan Tang, the Ministry of Science and Technology: 2012 China invested one trillion in R&D, up to the level of moderately developed countries, China News, December 24, 2012.

novation and an increase in the R&D/GDP ratio to 2.5% by 2020 – both of which are aimed at allowing China to become an advanced innovative country[11]. The emphasis on indigenous innovation is specifically designed to strengthen the local capacity for innovation among China's enterprises, thus helping to reduce Chinese dependence on foreign technology and helping to ensure that more of the IP needed to support technology development at all levels comes from domestic sources.

The MLP is divided into a series of core tasks as follows:

• Key areas and priority themes
'Key areas' refers to industries that require urgent S&T support to strengthen development of the national economy, society and national defense. 'Priority themes' address selected technology groups in key fields that need to develop a clear strategic development path, an improved technical foundation and greater use of recent breakthrough technologies[12]. The precise key areas and priority themes are:
– Energy;
– Water and mineral resources;
– Environment;
– Agriculture;
– Manufacturing;
– Transportation;
– IT and modern service industries;
– Population and health;
– Urbanization and urban development; and
– Public safety and national defense.

• Cutting-edge technologies
A series of cutting-edge technologies are specified as the building blocks for China's emerging knowledge economy. They include:
– Biotechnology;
– IT;
– New materials technology;
– Advanced manufacturing technology;
– Advanced energy technology;
– Marine technology;
– Laser technology; and
– Aerospace technology.

• Program for basic research
Under the MLP, basic research is to receive enhanced support. The key specified fields identified reflect the problems of cutting-edge science, fundamental research, major national strategic needs-oriented basic research and major scientific research programs.

The key areas and priority themes, the cutting-edge technologies and the program for basic research manifest the overall direction of China's technological development over the next decade[13].

"Decision on Accelerating the Development of Strategic Emerging Industries"

Along with the MLP, to promote the development of industrial technology innovation, China's State Council promulgated the "Decision on Accelerating the Development of Strategic Emerging Industries" in 2010. This important document lays out seven key sectors for emphasis as China restructures its economy away from the traditional manufacturing orientation that dominated economic activity during the 1980s and 1990s. Development of these seven industries must be closely aligned with the requirements of S&T development, the goal being to ensure that underpinning the growth and development of these industries is an enhanced array of domestic innovation capabilities. The specific foci for emphasizing the strategic emerging industries include fostering the development of energy-saving environmentally friendly know-how, a new genera-

11 "*National Medium-to-Long Term Science and Technology Development Plan* (2006-2020)", the State Council of People's Republic of China, 2006.
12 Ibid.
13 Ibid.

tion of IT, biotechnology, high-end manufacturing equipment, new energy technologies, new materials and a new energy-efficient automotive industry.

"12th Five-Year Strategic Emerging Industry Development Plan"

In July 2012, the State Council issued its "12th Five-Year National Strategic Emerging Industry Development Plan", which points out that China must maintain more than 20% annual growth rate across the proposed strategic emerging industries; the stated goal is for these seven strategic emerging industries to account for 8% of GDP by 2015. The priority attached to these seven key industries reflects Chinese assessment of the changing competitive landscape around the world and the fact that the future direction of international competition will be built around advancements in these specific sectors.

"Views on Deepening the Reform of Science and Technology Systems and Speeding Up Construction of the National Innovation System"

In assessing the country's overall progress since the onset of the MLP and the substantial addition of resources to support national S&T development, Chinese leaders have concluded that the net addition of material resources must be accompanied by further reforms in the management and operation of the S&T system at the national and local level. In other words, despite the transition from a situation of resource scarcity to resource abundance, R&D performance has continued to lag expectations. Accordingly, in July 2012, the National Science and Technology and Innovation Conference was held in Beijing. This conference brought together all the major stakeholders involved in China's innovation system; the gathering provided an opportunity for a serious critique of prevailing S&T practices and organization. In September 2012, the CPC Central Committee and the State Council jointly issued a major document entitled "Views on Deepening the Reform of Science and Technology Systems and Speeding Up Construction of the National Innovation System". The document highlights the strategic role of enterprise-driven technology innovation; it also explicitly lays out a number of key emphases designed to shape the direction and thrust of future S&T activities:

- Innovation-driven, services development;
- Stronger focus on corporate innovation and greater stress on collaborative innovation;
- Striking a better balance between government support and market orientation;
- Stronger system-wide coordination and reliance on legal instruments; and
- Adherence to the five basic principles of the reform and opening up, including continued reliance on international cooperation, but with a stronger orientation in the direction of 'win-win' outcomes.

The document also further clarifies the goals paramount to China's S&T development by 2020:

- To build a national innovation system for S&T development based on the principles of a socialist market economy with Chinese characteristics.
- Significantly improve the capacity for indigenous innovation and integrated innovation, as well as enhance capabilities for introduction, absorption and re-innovation.
- Achieve a series of original major S&T breakthroughs.
- Make great leaps in strategic high tech areas of R&D.
- Develop a number of innovations at world class levels.
- Optimize the overall innovation environment.
- Substantially increase the distribution of the benefits of innovation across society and the economy.
- Improve the quality of the national scientific and engineering talent base.

- Improve the capacity of leaders to drive economic and social development at both the national and local level to enable China to become an innovative, S&T nation[14].

The introduction of these policies and measures is designed to provide a strong impetus to the further development of China's innovation capabilities and overall progress in S&T. The clear motivation behind this renewed emphasis on unleashing the necessary forces to support the move to a more innovation-driven economy derives from the realization that not only has innovation become the new watchword in global economic and technology affairs, but also that those countries who fail to seize the high ground in this next phase in global technology advancement will not command a serious position of influence in international relations. The "UNESCO Science Report 2010" has pointed out that the gap between China and the world's S&T advanced nations has been narrowing, especially during the period of the 11th Five-Year Plan. Yet, while it is clear that China is steadily advancing towards its goal of becoming an innovation-oriented country by 2020, it also is facing a highly fluid, highly dynamic global innovation system that does not allow much time for careful pause or reflection.

Accordingly, it also is clear that Chinese leaders, including the new leadership team of President Xi Jinping and Premier Li Keqiang, realize that China is facing many challenges in the process of becoming an innovative country, including developing a still incomplete market environment; further strengthening protection of IP rights; overcoming financing difficulties that support small and medium enterprise-driven innovation; improving cooperation processes among those main organizations charged with supporting China's innovation agenda, including enterprises, universities and research institutions; and putting further investment in basic research[15]. To solve these problems, China must continue the process of S&T reform and opening up and deepen international cooperation in S&T to accelerate and promote the development of China's S&T and innovation capabilities and competencies.

U.S.-China S&T development comparison: Features and advantages

A comparison of U.S. and Chinese S&T planning processes and policies reveals numerous differences. This is not surprising given the readily apparent differences in history, culture, national values and political systems. Most importantly, the continued efficacy of these differences helps to explain both the reasons for some of the disconnects between the two nations in their approaches to innovation as well as the broad range of possible complementarities that hold great potential for forging enhanced cooperation now and in the future. An examination of several of these areas of difference and complementarities brings to the surface several key action points of possible importance to the leaders of both countries.

Overall strengths and level of commitment – superiority of the U.S. and China's rapid 'catch up' trajectory

The U.S. began to strengthen the components of its national innovation system after WWII and remains far ahead of most of the world in terms of past and present levels of S&T achievement. During the period since the mid-1980s, total U.S. national R&D investment has been more than the sum of all other Organisation of Economic Co-operation and Development countries. This huge investment in R&D has helped lay a solid material foundation for America's overall S&T advancement and capabili-

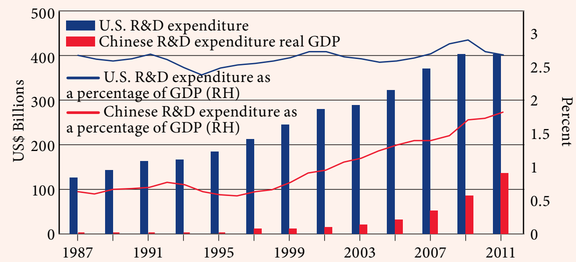
14 *The Opinions on Deepening the Reform of Science and Technology Systems and Speeding Up the Construction of the National Innovation System*, CPC Central Committee and the State Council, September 2012.

15 *UNESCO Science Report 2010: The Current Status of Science around the World,* United Nations Educational, Scientific and Cultural Organization, Paris, France, 2010.

ties. The U.S. has both breadth and depth in terms of its national S&T assets and knowledge base. At the same time, as a mature market-driven nation, generally speaking, the U.S. national innovation system exhibits a high level of overall effectiveness; its universities, national research institutes, enterprises and financial institutions have established a highly effective operating model after many years of practice. In addition, the American IP protection system, the set of antitrust regulations, and unfair competition laws and regulations largely provide a friendly environment for small and medium enterprises to grow and prosper, which helps to promote high-tech entrepreneurship and innovation along with a sustained series of national S&T advances.

China's current version of a national innovation system has been evolving since the period of reform and opening up began. Since the initial reforms were launched in the late 1970s, China's national innovation system has undergone a series of major reforms, including the first major S&T system reform initiative announced in March 1985; the 1999 structural reform of research institutes; and the 2006 launch of China's national long-term S&T development plan. The prevailing structure and operation of China's national innovation system is being shaped in important ways by the nature of the interface between its S&T system and its economic system – both of which are evolving in real-time. The interplay between economic and S&T reform provides the context for shaping the country's R&D environment and driving Chinese S&T development. More specifically, China's enterprises steadily, albeit gradually, are becoming the main drivers for execution and implementation of S&T innovation in China. In fact, across the entire geography of China at all levels, R&D investment is increasing rapidly. In 1996, national R&D investment accounted for 0.6% of GDP; since 1999, it has continued to grow at double-digit rates for several years. In 2011, China became the world's second largest R&D investment country after the U.S. By

Figure 1: R&D Expenditure and Its Share of GDP: A Comparison of China and the U.S., 1987-2011



Source: China Statistics Yearbook, China S&T Statistics Data Book, http://www.sts.org.cn/sjkl/kjtjdt/index.htm, Bureau of Economic Analysis, National Science Foundation

2013, China's R&D investment is expected to surpass RMB 1.0 trillion, accounting for close to 2% of GDP, with 70% of R&D investment provided by enterprises. Of course, quantity is no guarantee of quality, but this substantial addition of financial resources along with modernization of the physical infrastructure and growing Chinese high-end talent pool now offer the P.R.C. a serious opportunity to catch up with the West to a degree that would not have been possible in the past.

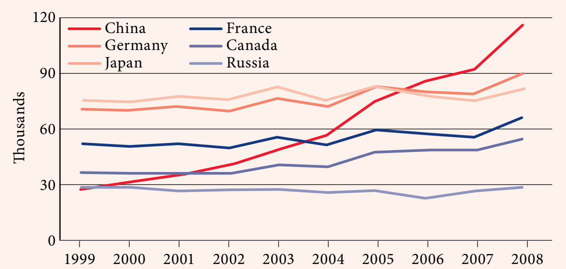
Figure 1 shows U.S. and China R&D investment levels and their respective shares of GDP. It can be said that the U.S. holds a greater advantage in terms of the absolute value of its annual R&D investment. At the same time, starting from a much smaller base and as a country in catch-up mode, China's R&D investment growth rate is leading the U.S. Clearly, the U.S. innovation system is more mature, which while offering many advantages, also presents some unique challenges in terms of introducing new changes into the prevailing system. With its concerted efforts to move sharply and steadily away from its previous reliance on a Soviet-style approach to R&D structure and operation, China's evolving innovation system seems less and less-plagued by prior existing legacy systems and baggage; in some ways, China may be better poised to experiment with new types of innovation models and to adapt itself to the changing requirements for launching and supporting the development of new emerging industries. The differences in the core strengths and system design across the respective innovation systems of the two countries seemingly provides a unique opportunity for both nations to promote new types of cooperation in S&T and create more win-win outcomes.

Basic research – the U.S. has a strong base in basic research while China is continuously strengthening its basic R&D efforts

One of the major objectives of the U.S. government is to maintain its leading position in basic research around the world. The proportion of basic research investment in the U.S. has consistently been relatively high. In 2009, basic research R&D accounted for 19% of total U.S. R&D investment of US$400.5bn, 53% of which has come from federal governmental funds. The bulk of basic research in the U.S. is usually conducted in research universities (53%) and national laboratories (15%). American research universities combine basic research and talent training together in ways that benefit the advancement of new knowledge creation. This is reflected by the fact that since the beginning of the 1950s, more than half of Nobel Prize winners (in fields other than literature and peace) have been from the U.S.

China's basic research has been plagued by a serious lack of investment in the past, with basic R&D investment accounting for around 5% of total R&D spending for many years. In recent years, however, with the implementation of the "Knowledge Innovation Project" and the "Construction of World-class Universities" initiative, China's basic research efforts have made some appreciable progress. The number of Chinese academic articles appearing in key international journals has been growing rapidly. As Figure 2 shows, the beginning of this century, the number of Chinese articles in major international journals placed China well behind most S&T advanced nations; since 2005, however, exclusive of the U.S., China began to surpass other nations and has become the second largest country in terms of the publication of international journal articles.

Figure 2: Annual Publications in Web of Science, 1999-2008



Source: Web of Science

A useful comparison of U.S. and China's basic research activities can be gotten from a review of their respective output of scientific papers. From the point of view of international publications, highly cited papers as well as those published in various respected scientific journals are an important manifestation of the quality and level of scientific research of a nation[16]. From 2005 to 2010, the average annual growth rate of highly cited papers worldwide was 4.9%, with the rate for China being 27.6% and the number of published papers reaching 5,264 (the figure for the U.S. was 56,299) – leaving China ranked seventh in the world. In 2010, China had 145 papers in the three major S&T journals (the figure for the U.S was 2,538), an increase of 84% compared with 2005. In fact, the total number of published papers in the three major journals was 358 less than in 2005, though China had an increase of 66 papers. As for the various world-class leading journals, the total number of published papers in 2010 increased by only 927 compared to 2005; China's increased by 3,406 papers in these journals during the same pe-

16 Highly cited papers are calculated based on statistics over a period of 10 years, and the number cited is ranked in the top 1% of papers in various disciplines; the three leading journals are: Cell, Nature and Science; the 'various leading journals in different fields' refers to these journals which have the highest impact factor. In general, according to Thomson Reuters published in "The Report of Journal Citation", there were 157 leading journals covering various disciplines in 2005; that number increased to 173 in 2010.

riod. In 2010, China published 5,203 papers in the world's leading journals (the figure for the U.S. was 21,296), ranking second in the world. From 2005 to 2010, the average annual growth rate of the number of Chinese papers published in the world's leading journals increased by 23.3%[17].

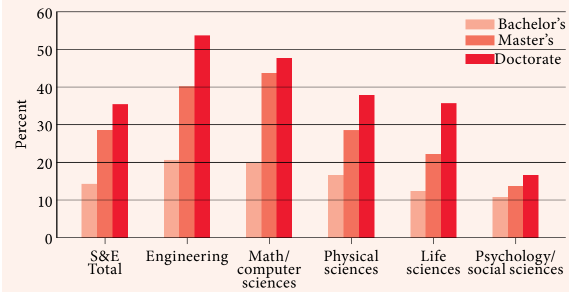
This shows that China's progress in basic research not only is reflected in the total output of scientific papers, but also in the quality of high level papers published in the world's leading journals. Clearly, Chinese scholars have achieved rapid growth in published papers. Nonetheless, compared with the U.S., the quantity of highly cited Chinese papers in the three major and world-leading journals – *Cell*, *Nature* and *Science* – only accounted for 9.3%, 5.7% and 24.4%, respectively of the U.S. totals. Obviously, the gap between the two countries remains considerable. For China to make a demonstrable leap in terms of the international impact of its ongoing scientific research activities, it necessarily will have to close this gap in the coming years. This means China's researchers will have to move into the mainstream of those trans-border, collaborative research networks that are now increasingly defining the cutting edge of new knowledge creation.

S&T Human Resources – the US high-level scientific and engineering (S&E) talent base and its continued dependence on overseas migration versus China's abundant S&T human resources

The supply, demand and utilization of S&E human resources are an important determinant of national S&T development. In general, America's S&E human resources are growing faster than its overall employment growth, though in 2010, the percentage of jobs in this field dropped to 4.9% from a high of 5.3% in 2000 – the first such decline since 1950. Over the past 25 years, the number of S&E human resources has grown sharply, reaching about 6.65 million people in

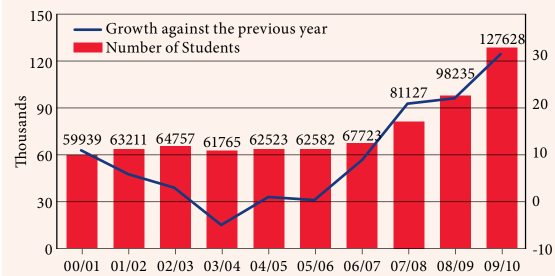
17 Defang He, "The Comparative Study of Chinese High-impact Papers", *China Soft Science*, 2011, issue 9, pp. 94-99.

Figure 3: Percentage of Foreign-born S&E degree holders in the U.S. by field and level of S&E degree, 2008



Source: Science and Engineering Indicators 2012, U.S. National Science Foundation

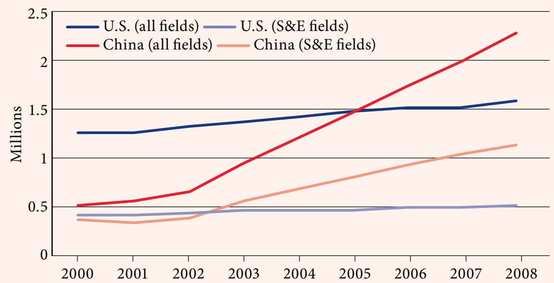
Figure 4: Number of Chinese students in the U.S., 2000-2010



Source: Open Doors: Report on International Educational Exchange, Institute of International Studies

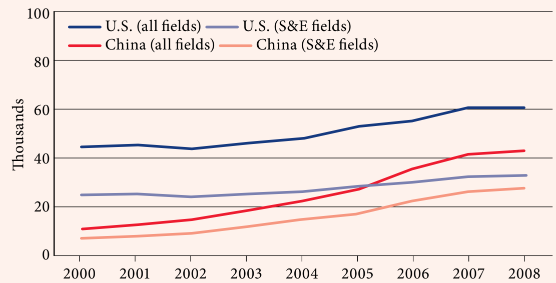
2010. One of the hidden shortcomings across the U.S. S&E human resource pool is the country's apparent dependence on foreign talent migration to meet its need for S&E expertise. The figures above, which are from a survey of American S&E personnel published in 2012, show the statistics for 2008. According to Figure 3, the proportion of foreign-born talent across the different fields and levels of the S&E talent pool is quiet high. For example, in the field of engineering, more than half of the doctoral students, 40% of the master's students and 20% of the undergraduate students are foreign born. It is the same situation in such key fields as mathematics and computer science. Not surprisingly, among foreign-born S&E doctoral students, the percentage of mainland Chinese is quite high. Since the late 1970s, a large number of Chinese students went to the U.S. to pursue graduate degrees in S&E; the overall number has been growing steadily year by year, though there was a decline in

Figure 5: **First University Degrees in the U.S. and China, 2000-2008**



Source: Science and Engineering Indicators 2012, US National Science Foundation

Figure 6: **Doctoral Degrees in the U.S. and China, 2000-2008**



Source: Science and Engineering Indicators 2012, US National Science Foundation

Figure 7: **China's S&T Talent – Current Situation and Development Goals***

Year	R & D personnel (10,000/year)	R & D researchers (10,000/year)	R & D personnel per 10,000 labor force (person/people)	R & D researchers per 10,000 labor force (person/people)	R & D personnel per capita R&D expenditure (10,000s)	R & D researchers per capita R&D expenditure (10,000s)
2008	196.5	105.0	24.8	13.3	23.5	44.0
2015	280	150	33	18	38	71
2020	380	200	43	23	50	100

* *"15-Year National Medium to Long-Term Science and Technology Development Plan (2006-2020)", the State Council of the P.R.C., 2006.*

Source: the Compendium of National Medium-and-Long-Term Plan for Education Reform and Development (2010-2020)

the growth of graduate students in 2012 to 2013. Figure 4 shows the growth of Chinese students studying overseas in the U.S. between 2000 and 2010.

Compared with the U.S., Chinese colleges and universities also have trained a large number of S&E students and technology personnel every year. The number of first university degrees awarded by universities in China has exceeded that by American universities. University enrollment used to be quite low in China until the policy of expansion of college education was implemented in 1999. Chinese universities conferred a similar number of doctorate degrees in S&E fields as their American counterparts in recent years. However, if all fields are taken into account, doctoral degrees offered by U.S. universities still were significantly more than those by Chinese universities (see Figures 5 and 6).

According to the forecast contained in the MLP, the total number of Chinese R&D personnel is projected to increase from 19.65 million in 2008 to 38 million by 2020. The number of R&D personnel will increase from 10.5million per year in 2008 to 20 million per year. And, the percentage of R&D personnel and R&D researchers per 10,000 workers is projected to increase from 24.8% and 13.3%, respectively, in 2008 to 43% and 23% respectively, by 2020 (see Figure 7). China is going to attain new heights in the supply of talent in the fields of equipment manufacturing, IT, biotechnology, new materials, aerospace, marine, ecological and environmental protection, new energy and agriculture technology.

It can be seen from the data above that China already possesses a large S&T human resource pool that have mainly gone through its own training and education system. That said, every year, a growing percentage of China's S&T talent pool head abroad for undergraduate and graduate study; a percentage of this group has decided to remain abroad after completing their studies. This pool of talent helps to support the U.S. need for scientists and engineers, with an appreciable proportion of this group being ethnic Chinese[18]. It must also be recognized that this group has a strong tendency to stay engaged with China's research establishment through special programs such as the "One Thousand Talents Program" as well as through affiliated appointments at various Chinese universities. Many U.S.-based scientists and engineers who are part of the Chinese diaspora have government-sponsored projects in China and are training groups of mainland Chinese graduate students, thus serving as a bridge between the American and Chinese scientific communities.

Space exploration – the U.S. remains the most influential player leading China and the rest of the world

The U.S. has had a commanding position in space exploration since the mid-20th century. It has a long and impressive track record of successful space-related initiatives, such as the launch of satellites, the manned space program, and the Moon and Mars exploration. One of the most influential achievements of the U.S. Space Shuttle is the assembly of the International Space Station that has been serving as a multi-purpose observatory and research laboratory for astronauts and cosmonauts from various countries. China, for its part, has made steady progress in its space capability over the past decade. The number of manned space flights launched by China has grown in recent years, although it still lags behind the U.S. and Russia[19]. 2012 witnessed China's successful manned rendezvous and docking technology with the Tiangong-1 orbital vehicle. However, U.S.-China cooperation in space exploration, whether in the form of policy dialogue on space, information sharing or other joint activities, remains limited.

18 *UNESCO Science Report 2010: The Current Status of Science around the World,* United Nations Educational, Scientific and Cultural Organization, Paris, France, 2010.

19 Jeffrey Logan, "China's Space Program: Options for U.S.-China Cooperation", Congressional Research Service Report for Congress, Sep 2008, http://www.fas.org/sgp/crs/row/RS22777.pdf.

S&T consumer market – America's mature domestic market versus China's large potential market – which has created a dynamic 'market surge effect'

When it comes to the consumer market for high-technology goods and services, the U.S. market remains a relatively stable source of demand, while China, with its large and increasingly prosperous population, provides a potentially huge market opportunity for advanced technology products and services. With the growth of the Chinese 'middle class', there has been an appreciably rapid increase in demand for high-quality, more sophisticated technology products and services in China. It can be seen from the success of Apple products in China that the overall gains in GDP growth have helped drive the emergence of a huge, still-growing consumer market. According to Apple's fiscal report (second quarter of 2012), its revenue in the Greater China region has tripled, reaching a record of US$7.9bn, equivalent to about RMB49.8bn, which accounted for 20% of its total worldwide revenue. During this same period, Apple earned RMB550m in revenues every day from the Chinese market. According to Apple's own market reporting, the Chinese market has a huge and growing demand for the iPhone 5 and iPad 3. The sales total for the iPhone is four times more than the same period last year (data is for the iPhone 4 and 4S). Apple's Mac retail sales have grown more than 60% over the same period. Currently, Apple has over 1,800 Mac retail stores, 11,000 iPhone retail stores and 2,500 iPad retail stores[20]. Even taking into account some of the strong criticism of Apple in the Chinese media during the first several months of 2013, this success highlights the emergence of a 'market surge effect' for sophisticated technology products and the enormous remaining business opportunities for other U.S. firms operating in this same market space.

20 "Apple sales 550 million every day in China; iPhone sales increased 4-fold", *First Financial Daily*, 26 April 2012.

Figure 8: **International Patent Applications and Ranking of Main Countries*, 2006-2010**

2006		2007		2008		2009		2010	
Rank	Applications	Rank	Applications	Rank	Applications	Rank	Applications	Rank	Applications
U.S.	51280	U.S.	54043	U.S.	51637	U.S.	45618	U.S.	44855
Japan	27025	Japan	27743	Japan	28760	Japan	29802	Japan	32166
Germany	16736	Germany	17821	Germany	18855	Germany	16797	Germany	17171
France	6256	Korea	7064	Korea	7899	Korea	8305	China	12337
Korea	5945	France	6560	France	7072	China	7900	Korea	9686
U.K.	5097	U.K.	5542	China	6120	France	7237	France	7193
Netherlands	4553	China	5455	U.K.	5466	U.K.	5044	U.K.	4857
China	3942	Netherlands	4433	Netherlands	4363	Netherlands	4462	Netherlands	4097

* *"Analysis on 2010 PCT Patent Application for World Development Trend and Characteristics of Chinese",* Chinese Inventions and Patents, *2011, issue 5, pp. 33-36.*

Source: Analysis on the 2010 World Trend in PCT Application and China's Features. China Invention & Patent, *2011 (5): 33-36*

Enterprise innovation capability and competitiveness in the international market – U.S. leading enterprises and the steadily expanding presence and growing strength of Chinese enterprises abroad

America's high-technology enterprises retain a strong presence in global markets and continue to offer a range of sophisticated, cutting-edge products and services that define the frontier in many consumer and industrial product categories. U.S. technology-based firms maintain a vast array of core business and technology competencies that afford them leading positions across the world in clean energy, bio-pharmaceuticals, IT, aerospace, high-end manufacturing and military industries. On 4 December 2012, Thomson Reuters ranked the top 100 global innovation companies based on their overall number of patents, patent licensing success rate, global coverage of their patent portfolio and the influence of their patent citations. The U.S. was at the top of the list with 45 American companies (including U.S. governmental agencies). Japan had 25 companies, the E.U. had 21 and South Korea had seven companies.

Chinese high-tech enterprises have been expanding rapidly over recent years. Since 2006, the number of China's international patent applications to the Patent Cooperation Treaty (PCT) has witnessed sustained and rapid growth; China has become the world's fastest growing country in international patent applications over the past few years. China ranked eighth in terms of PCT applications in 2006; it surpassed the Netherlands ranking of seventh in 2007. China then surpassed the U.K. ranking of sixth in 2008 and in 2009, China surpassed France and ranked fifth. In 2010, China surpassed South Korea and ranked fourth in the world. In 2010, there were 12,337 Chinese PCT applications, reflecting an increase of 56.2% over 2009 (see Figure 8). Many Chinese companies such as Huawei, ZTE, CNPC, etc. also are among the leaders on the list of international patent applications. Of course, quantity is no predictor of quality, and there remain some serious concerns among international observers about the commercial value – real and potential – of Chinese patents. Moreover, even with these appreciable increases in IP generation, the fact is that China remains a major importer of new know-how, while the U.S. still retains its leadership position as a generator of commercially relevant new knowledge. In 2009, for example, according to International Monetary Fund data, China experienced a US$10bn deficit in its IP rights balance of payments, while the U.S. had a US$64bn surplus.

Assessment and Stocktaking

According to their different stages of development and the unique characteristics of their respective technology systems, it is not difficult to understand why these two nations might have strong prospects for meaningful, mutually beneficial long-term S&T cooperation, especially if they are able to harness their strong complementary advantages across many S&T fields of common interest. The U.S. potential in the domain of applied S&T is especially strong given its substantial capabilities and extensive experience with the commercialization of research. More specifically, the U.S. could gain appreciable market share in China and seize many emerging opportunities by relying on its acknowledged core competitive strengths; American firms can leverage their potential successes in the Chinese market to enhance their overall competitive positions elsewhere around the globe. China, which once stood at the margins of global competition, now stands center stage; commercial success in China can help supply the revenue needed to help U.S. firms open up new markets elsewhere as well as support existing industries that have been affected by the maturation of markets in the advanced industrial countries. For China, its academic community and business sector are moving through a catch-up period as part of their country's overall S&T development. Cooperation with the U.S. can enhance the overall pace of S&T acceleration and industrial upgrading. It also can help China keep up with the speed of S&T globalization. In addition, Chinese companies can learn from their U.S. counterparts about how to establish a more innovative, forward-looking corporate culture and philosophy. Moreover, through increased contacts and cooperation, China can also deepen its knowledge and understanding of the role and management of technology in driving long-term corporate competitiveness. All of this new knowledge can help facilitate the further transformation of China's economy and society as well as its R&D system.

On the other hand, if these two nations miss these apparent opportunities for extending their cooperation, Chinese enterprises will necessarily have to turn to other corporate and industrial regional partners during this important time in their own technological transition. Given such a possible turn of events, China might begin to view the U.S. in more adversarial terms, viewing the U.S. much more as a strategic competitor rather than as a long-term strategic partner. Catching up with the U.S. could increasingly be seen in zero-sum terms. For the U.S., it would lose an important opportunity to shape and influence the future development of China's economy and S&T system; it also could conceivably lose out on some of the benefits to be derived from closer articulation with the Chinese economy as the P.R.C. moves into its next stages of development. Current differences in understanding and perspective regarding trade protection and export restrictions, in particular, are specific barriers between the two countries that could become a more serious bottleneck to meaningful, sustained cooperation. The tangible and growing levels of economic and technological interdependence between the world's two largest economies is undeniable; they both have shared in the benefits derived from their high level of integration in terms of commercial affairs, academic and S&T exchanges, etc. A souring of the U.S.-China bilateral relationship from a political perspective, would almost certainly transform their engagement from the current, largely win-win orientation to more of a zero-sum game – leaving both countries with many lost opportunities, especially in terms of their ability to work together to address many of the world's pressing problems.

U.S.-China S&T Exchanges and Cooperation: Experience and Future Trajectory

Review of U.S.-China S&T exchanges and cooperation since the establishment of diplomatic relations three decades ago

Formal education exchanges and S&T cooperation between the U.S. and China started in 1979. In January 1979, former Vice Premier Deng Xiaoping and former President Jimmy Carter signed the "US-China Inter-governmental Science and Technology Cooperation Agreement", which has served as an important guiding document for driving S&T cooperation between the two countries for more than 30 years. According to the terms of this agreement, the U.S. and China established a Joint Commission on U.S.-China Cooperation in S&T (JCM); the two countries also signed an equally important agreement to promote and facilitate exchanges in education as well.

As a result of the signing of these documents, China began to select and send a large number of students and S&T professionals to the U.S. for advanced training. Up to 1989, the governments had signed numerous S&T cooperation agreements, protocols and memoranda of understanding involving 27 subareas such as management, transportation, aviation, nuclear and biomedical sciences. Since that time, based on the framework provided by the "US-China Inter-governmental Science and Technology Cooperation Agreement", the two nations have initiated more than 50 cooperation projects, protocols and memoranda of understanding in the fields of high-energy physics, space, atmospheric, marine, medical health, transport and energy. The broad areas of bilateral cooperation include energy, environment, agriculture, basic sciences, IT, S&T policy, transportation, health, medicine, nuclear safety and civil nuclear technology, materials science, metrology, biomedical science, earthquake science and geology, oceans, atmospheric sciences and medicine.

The main mechanisms for carrying out cooperation include collaborative R&D, joint investigations, technology transfer, technology demonstrations, data exchange, academic conferences, technical advice, personnel exchanges, etc. Some important achievements include a Remote Sensing Satellite Ground Station, the Beijing Electron-Positron Collider and the China Digital Seismograph Network[21]. Following the principles of equality, mutual benefit and reciprocity, the two governments have supported continued expansion of the bilateral S&T relationship.

In many ways, the S&T relationship has expanded far beyond the government-to-government ties that were formalized in the bilateral accord; today, U.S.-China S&T cooperation includes universities and their faculty, thinktanks, corporations and many non-governmental organizations. Most important, the S&T cooperative relationship has continued to thrive even in the midst of ongoing disagreements in the political arena; in fact, the S&T relationship has served as one of the most important vehicles for building long-term trust and cross-cultural understanding between professionals from both countries.

Since 2000, in particular, U.S.-China education and S&T cooperation have proceeded at an accelerating pace. Through the JCM and other numerous channels for S&T engagement, both nations continue to seek out new areas for expanding their cooperative ties and have reinforced their commitment to sustain the bilateral S&T relationship. As a result, cooperation now includes such new fields as second generation internet technology, high-energy physics, nuclear physics and magnetic confinement fission, surface water hydrology, electric car and fuel cell vehicle technology development, advanced reactor technology, etc. In fact, it is safe to say that U.S.-China S&T cooperation has become one of the

21 Xinhua Newsagency, "US-China S&T Cooperation", http://news.xinhuanet.com/ziliao/2002-01/28/content_257226.htm

highlights in the overall bilateral relationship and now includes a significant and growing number of active constituencies and committed stakeholders on both sides of the Pacific Ocean.

As suggested earlier, U.S.-China S&T cooperation has helped the two countries overcome many cultural and institutional differences and has withstood the impact of political tensions that have arisen from time to time between Washington and Beijing, including the June 1989 Tiananmen Incident, the 1999 accidental bombing of the P.R.C. Embassy in Yugoslavia and the 2001 EP-3 air collision incident in the South China Sea, etc.

The following highlights some of the major achievements in U.S.-China S&T cooperation in terms of the focus of cooperation, local government cooperation, enterprise R&D initiatives, jointly published S&T papers and monographs, and S&T personnel training.

Focus of cooperation

The two nations have made useful progress in agricultural S&T, clean energy, bio-medicine, wireless communication technology, etc. Taking U.S.-China agricultural S&T cooperation as an example, the two countries signed a formal protocol in 2002 under the umbrella of the overall "US-China S&T Agreement". Within a decade, U.S.-China agricultural S&T had made great strides. A joint working group mechanism was established and seven priority areas of cooperation were identified, including management of natural resources, agricultural biotechnology, agricultural water-saving technology, processing of agricultural products, food safety, dairy production and processing and biofuels. Nine joint research centers were formed. More than 50 international S&T cooperation projects were carried out, more than 100 graduate students and young researchers received training, and a series of high-level international academic conferences and seminars were held. In addition, a broad range of S&T academic exchanges in agriculture have been carried out. The direction of future activities will be in the fields of agricultural biotechnology, water-saving agriculture and gene bank collection technology and practice[22].

Cooperation between the two nations in agriculture has helped U.S. enterprises enter the Chinese market and gain an important share in selected product areas. Also, it has provided unprecedented opportunities for U.S. agricultural S&T and product exports to China. At the same time, China's agricultural production know-how has shown great improvement through the absorption and assimilation of U.S. advanced technology and joint R&D activities. Both countries clearly have benefitted from their strong relationship in the field of agricultural S&T cooperation and it is likely this will continue to be a field that both sides find attractive and mutually rewarding.

Local government S&T cooperation

In addition to national level cooperation, S&T cooperation between local governments has yielded some important results and holds great potential for expansion in the future. Cooperation between local level entities tends to be more complementary, with each side bringing something unique to the table. For example, under the auspices of a collaborative agreement between Qinghai province and the Utah state government, the two sides have become the only U.S.-China Green Partnership approved by the U.S. State Department and China's National Development and Reform Commission (NDRC) in May 2011. The two sides established a formal sister relationship in July 2011 and at the same time, the Provincial/State Governors Forum was held in Salt Lake City. The foci of cooperation include international technology transfer as well as R&D commercialization, both of which are embodied in the joint establishment of a cooperative innovation hub. Under the umbrella of both the national and local cooperation mechanisms, the

22 "Ten Years Achievements of the China-US agricultural cooperation in science and technology", *S&T Daily*, August 22, 2012

two sides have also launched a comprehensive, multi-level, multi-field range of cooperative activities. Breakthroughs in cooperation have been achieved in the fields of IP rights, the establishment of overseas R&D bases, the commercialization of R&D results and technology transfer demonstration projects, etc. Based on the cooperation between Utah and Qinghai, Utah also has developed cooperative relationships with several other P.R.C. provinces, including several provinces in Western China[23].

Enterprise R&D activities

R&D investments into China by foreign multinational companies have grown sharply over the last decade. U.S. multinational corporations have more R&D centers than any other foreign companies operating in China. Currently, there are more than 130 U.S. R&D centers in place in Beijing, which is the top location in China for foreign R&D activity. The U.S. share accounts for about 36% of all foreign R&D centers in Beijing[24]. U.S. multinational corporations also have set up approximately 100 R&D centers in Shanghai, accounting for one third of all foreign R&D institutions in Shanghai – double that of Japan – with 45 R&D centers. Some of the U.S. R&D units operating in China have upgraded their activities from a focus primarily on adaptation of existing products for the Chinese market to a focus on East Asia and even global markets. Some R&D centers are heavily engaged in core S&T research services for international markets, including companies such as HP and the Microsoft Asia Research Center. A large number of U.S. enterprises are growing their presence in China to include R&D centers so that they can reduce their R&D costs and improve the competitiveness of their products. While there is some concern in China about a so-called ‘internal brain drain’, whereby appreciable numbers of Chinese returnees are choosing to work in foreign rather than local R&D organizations, the fact is that the presence of such foreign R&D centers provides numerous opportunities for positive spillover effects and externalities that are well aligned with China's goal of strengthening the overall domestic innovation system.

23 Thanks for the information provided from Mr. Hu Xiangqian at “Green Partner” Utah - Qinghai Western Union office.
24 Followed by the E.U. which accounts for about 24%; Japan which accounts for about 20%; and Hong Kong and Taiwan which account for about 10%.

Figure 9: Internationally Co-authored S&E Articles – World, China and the U.S., 1995 and 2010

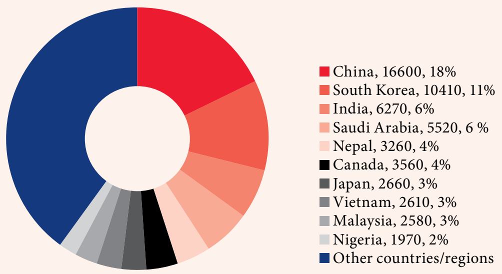
	1995	2010	Percentage change
World-World	79,128	185,303	134.18%
U.S.-World	36,361	79,581	118.86%
China-World	2,914	24,164	729.24%
U.S.-China	1,112	10,917	881.74%
The share of U.S.-China papers in U.S.-World	3.06%	13.72%	•
The share of U.S.-China papers in China-World	38.16%	45.18%	

Source: Science and Engineering Indicators 2012, U.S. National Science Foundation

Co-authored S&T papers and monographs

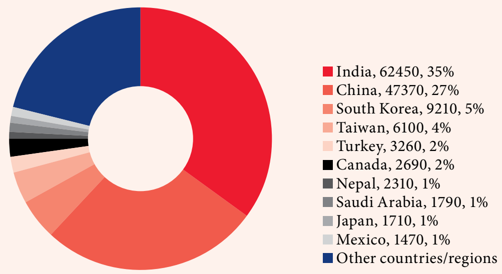
Traditionally, the U.S. has always been the most important partner in producing co-authored papers. As Figure 9 shows, the number of co-authored science and engineering papers between China and the U.S. has been growing very rapidly over the last two decades. Specifically, the share of U.S.-China co-authored papers among the total number of co-authored papers of the U.S. with all countries rose from 3% in 1995 to over 13% in 2010. On the U.S. side, China ranks seventh on its list of foreign partners for co-authored papers. In recent years, scientists from both countries have increased the number of co-authored papers in the fields of chemistry, nano-science, and gene and cell biology. Taking nano-science as an example, in 1996, there were only 16 papers co-authored by U.S. and Chinese scientists in this field, while there were 86 by U.S. and German authors, 65 by U.S. and Japanese, and 43 by U.S. and Russian scientists. In 2005, collaborations between U.S. and Chinese scientists ranked first in this field with 293 papers, surpassing Germany with 269 papers, Japan with 202 and South Korea

Figure 10: Foreign Undergraduate Science and Engineering Student Enrollment in U.S. Universities, by Selected Places of Origin, Nov 2010



Source: Science and Engineering Indicators 2012, US National Science Foundation

Figure 11: Foreign Graduate S&E Student Enrollment in U.S. Universities, by Selected Places of Origin, Nov 2010



Source: Science and Engineering Indicators 2012, US National Science Foundation

with 195[25]. Increasing numbers of U.S.-China co-authored papers are published in leading academic journals with high impact. This reflects the growing depth of high level U.S.-China S&T cooperation in many scientific fields.

S&T personnel training

The U.S. stands as the most important destination for Chinese students engaged in overseas study. During the 2009-2010 academic year, there were 127,628 Chinese students in U.S. higher education institutions, an increase of 29.9% over 2009. Chinese students accounted for 18.5% of the total number of international students in the U.S., surpassing India – which was 15.2%. China has become the primary source country for international students in the U.S. Chinese students also account for the largest proportion of foreign undergraduate S&E students in U.S. universities (see Figure 10). For foreign S&E postgraduates, China is the second largest source behind India. In 2012, according to the Institute of International Education, the number of Chinese students studying in the U.S. reached over 194,000. While not all of these students are coming from top-tier universities or high schools, a significant proportion are coming from some of China's best schools and colleges, giving the U.S. access to some of the brightest young minds in China. In recent years, with the rapid development of China's economy and the "Introduction of the Overseas High-level Talents Plan", (referred to as the Thousand Talents Program) and other talent attraction policies, the number of Chinese students returning home has started gradually to increase. This cadre of returning talent represents an important catalyst for upgrading Chinese S&T and innovation efforts. Some of these returnees have secured employment with Chinese organizations, while, as noted, a substantial percentage also have gotten jobs with U.S. (and other) multinational firms operating manufacturing and R&D centers in China. Obviously, a portion of these returnees represent an important potential vanguard that will drive China's innovation system in the years ahead.

From an overall perspective, it is clear that both the U.S. and China attach great importance to S&T cooperation. The priority attached to the bilateral S&T relationship is reflected in the fact that S&T cooperation has become a top priority within the U.S.-China Strategic and Economic Dialogue (SED). Both sides have supported the establishment of an ongoing 'U.S.-China dialogue mechanism'. After several dialogues, the two sides have realized some significant outcomes, including the establishment and implementation of a U.S.-China Clean Energy Research Center, the creation of a U.S.-China agricultural innovation program, a U.S.-China initiative for pro-

25 Bihui Jin and Richard P. Suttmeier, *Sino-US S&T Cooperation: Bibliometrics Analysis*, Ministry of Science and Technology major basic research pre-special (2004CCC00400); U.S. National Science Foundation-funded project (0IsE 0440423), 2007.

tection of the environment, bilateral cooperation in health and a U.S.-China natural sciences foundation. These projects have secured about a US$20bn investment from enterprises for projects such as third generation nuclear power, China's UHV transmission, U.S.-China S&T eco-park, and an integrated gas-steam combined cycle (IGCC). The nature of cooperation has gradually but steadily begun to tie together cooperation in S&T with economic and commercial cooperation.

Considering the future of U.S.-China S&T cooperation, there appear to be a range of new popular areas for expanding the ties between the two countries. For example, in the field of third generation nuclear power, the U.S. and China have set up a 50-50 joint venture company to promote the third generation development of nuclear power technology around the world. In the field of IGCC, China appears to have the strongest technology in coal-gas transformation, while the U.S. ranks first in the world in steam turbine technology. The U.S. and China could achieve more in-depth cooperation using the complementary advantages of each country to achieve more 'win-win' outcomes. In addition, if they can overcome their respective political concerns about dealing with global climate change, the two nations potentially have a great deal to gain from expanded cooperation in the fields of carbon capture, utilization and storage (CCUS).

Win-win cooperation: cooperation mode and key areas

While S&T cooperation between the U.S. and China has yielded substantial results over the past decades, looking to the future, there still is plenty of room for new cooperative initiatives between the two countries. From an overall macro perspective, however, there still remains a pressing need to strengthen mutual trust in the political and military realms between Beijing and Washington. Otherwise, more comprehensive cooperation in S&T between the U.S. and China is unlikely to occur. On the other hand, a scenario that sees a reduced level of cooperation from the current level appears to be unlikely as well – unless political tensions flare up over such issues as Taiwan, the South China Sea or cyber security. Such a change would be contrary to the historical trends over the last three decades, would be inconsistent with the high level of interdependence between the two nations and would mark a return to the Cold War mentality that seriously divided both countries between 1949 and 1979. The result would be a major loss for both nations. Accordingly, the more likely scenario is that the two countries will maintain, at a minimum, the existing levels of cooperation (even if there are changes in emphasis) while striving to achieve a breakthrough in terms of the expansion of local cooperation. The possible modes for future expanded cooperation include:

Enterprise-centered Business to Business

Barring any major changes in the international and regional economic environment, American firms are likely to continue their enthusiasm for participating in China's huge domestic market by utilizing their advanced technologies and marketing expertise to capture greater market share. This will further drive 'the market surge effect' within China's consumer and industrial markets in communications and IT, bio-pharmaceutical and other technology-driven industries. Apple and Johnson & Johnson's successful performance in China are good examples of U.S. firms that have been able to enter the Chinese market through a combination of product-driven and market-oriented strategies. Meanwhile, with the increasing prominence of foreign investment by Chinese enterprises around the world, it is quite likely that more and more P.R.C. companies will seek to invest in high-tech fields in the U.S. The U.S. and Chinese governments will need to negotiate a more normalized path to reduce barriers to such investment and to allow the market mechanism to play the primary role for screening potential investment projects. Chinese enterprises, such as Huawei and ZTE, should pay ample deference to the U.S. government's concerns about national security and fully cooperate by providing ample information about their firms and their operations. Both governments as well as those firms involved will need to ensure greater transparency on a regular basis as well as balanced treatment of all parties in general.

Official cooperation mode actively promoted by governments at all levels

Government promotion is another important factor in achieving meaningful bilateral S&T cooperation. Government promotion is not limited necessarily to the level of the U.S. federal government or the Chinese central government; policies to promote cooperative and business opportunities by state and provincial governments are also critically important. For example, the U.S. and China can use a multi-level government-level approach to advance agricultural cooperation, environmental protection and clean energy. The U.S., for example, has multiple opportunities to promote U.S. technology transfer to China to help solve the P.R.C.'s food security problems and to better tackle the problems of global climate change as well as other similar global issues. The advantage of broad-based government promotion is that it is led by government agencies at all levels to encourage participation of specific targeted groups or geographic areas. However, this mode of cooperation must ensure that it is sustainable. Incentives to attract the required types of private sector and academic participants must be well designed to ensure that there are meaningful gains for both sides from the proposed cooperation.

Cooperation between U.S. and Chinese universities and research institutes

U.S. universities and research institutes engaged in overseas S&T cooperation can be divided into two categories. First, there are those who are driven by government-led promotion efforts; they often are attracted by some type of project-oriented cooperation in a specific research field. The second category of participants often engage in cooperative activities that emerge opportunistically rather than through a concrete plan or promotional effort. Within the framework of U.S.-China S&T cooperation, the first form of cooperation accounts for the majority of cases; they tend to be highly targeted, have strong resource support and thus usually yield more substantial results. Within the Clean Coal Technology League formed under the framework of the U.S.-China Energy Efficiency Alliance, for example, the U.S. side is represented by a group of universities and research institutes – led by the University of West Virginia – that also includes the University of Kentucky, the University of Wyoming, the Los Alamos Laboratory, the Lawrence Livermore International Laboratory, the U.S. National Energy Technology Laboratory and the World Resources Institute. The Chinese side is led by Huazhong University of Science and Technology in Wuhan, with the other participants including Tsinghua University, Zhejiang University, Shanghai Jiaotong University, the China University of Mining and Technology, Northwestern University, Jinan University and the Shaanxi Energy and Chemical Research Institute.[26] American universities and research institutions have core strengths in the R&D area; these advantages form the crux of their attractiveness within the framework of U.S.-China bilateral cooperation. Through this approach to cooperation, the two sides are working together to address critical global energy issues; they are leveraging outstanding S&T talent from both the U.S. and China. In addition to developing a mutually productive dialogue and participating in world class R&D activities, both sides hope to achieve substantial technical progress that results in meaningful commercial breakthroughs.

It is not difficult to recognize from the above discussion that the focus areas and priorities select-

26 China's Ministry of Science and Technology, "US-China Clean Energy Research Center 2011 Annual Report", 2011.

ed for bilateral cooperation have a strong linkage to the key fields and sectors mentioned in China's MLP. As noted, the MLP gives strong emphasis to advances in agriculture, clean energy, bio-medicine, communications, IT and other key industries – all of which are specific S&T strengths in the U.S. As suggested earlier, America's advanced technology base, combined with China's huge 'market surge' can yield significant benefits to both sides; clean energy, bio-medicine and nanotechnology are the 'Blue Ocean' sectors for U.S. and China cooperation in the 21st century. If properly managed and kept reasonably insulated from the often cantankerous ebb and flow of political relations, U.S.-China S&T cooperation can bring substantial benefits to both countries and the world as a whole.

Case study: U.S.-China energy cooperation – mutual benefit and win-win cooperation

With respect to the promotion of clean energy technologies, the U.S. and China share a plethora of common strategic and economic interests. The U.S. and China both face many common challenges in the energy field; both countries recognize that safe, economical and clean energy is extremely important to their future economic prosperity and sustainability. To address their common challenges, the U.S. and China have recognized the need to adopt a forward-looking energy strategy based on harnessing the potential gains from joint research and technological innovation. The future economic growth and development of the two countries depends heavily on the use of innovative production techniques and the efficient use of clean fuel and clean electricity; energy S&T cooperation between the two countries has the potential to create a series of mutually beneficial outcomes and win-win results[27].

The U.S.-China Clean Energy Research Center (CERC) is a consortium that was established in 2009 as a joint effort between the U.S. and Chinese governments. The center was inaugurated to build a solid platform to deepen U.S.-China cooperation in energy S&T; its existence reflects the strategic importance that both countries attach to collaborate on approaches for developing new and clean energy technologies. Under the CERC framework, both sides have confirmed the center's three core components: industry, education and research. The core areas of cooperation include the Advanced Coal Technology Consortium (ACTC), the project on Building Energy Efficiency (BEE) and the Clean Vehicle Coalition (CUC); the two countries have invited nearly 100 companies, universities, research institutes and national laboratories to participate in the work of the three units.

The CERC is actively engaged in the process of developing clean coal technology, building energy-saving technologies and clean vehicle technology; these technologies are the core elements of the two countries' respective energy strategy. These technologies will ensure a cleaner, more energy-efficient future for the U.S. and China by reducing dependence on imported crude oil, improving air quality, promoting economic growth by reducing energy costs and also reducing total global energy production and use – all of which will have a positive impact on the overall global environment[28].

While the work of CERC only formally began in 2011 – after the completion of a path-breaking, major agreement on IP rights – the center already has produced some tangible achievements, including the following:

- The formation of a strong management system, including the establishment of a formal leadership and supervision mechanism;
- Development of a detailed implementation plan

27 Ibid.

28 Ministry of Science and Technology Evaluation Center, "Mid-term Evaluation Report of the U.S.-China Clean Energy Research Center", 2012.

that was drawn up jointly to strengthen overall coordination;

- Outline of a joint investment program for the private sector and the respective governments;
- Promotion of a series of long-term research partnerships; and
- Output of a collection of significant technical results in terms of both R&D and pre-commercial technologies.

The total investment by the U.S. and China will reach US$150m spread over five years[29]. Clearly, this is a relatively modest investment; what is more important is the chance to prove the long-term utility of meaningful and deeper S&T cooperation. CERC will promote collaborative approaches in clean energy technology research, development and commercialization. With complementary advantages in both technology and talent, the jointly managed center will help the two countries ensure a prosperous future by reducing dependence on fossil fuels and expanding reliance on clean, efficient new types of new energy.

Problems and Frictions in U.S.-China S&T Exchanges and Cooperation

Due to the apparent differences between the socio-political systems and development experiences of these two continental-sized economies, it is probably inevitable that a number of significant frictions and tensions have emerged in the context of their overall bilateral scientific and technological exchange and cooperation activities. In many respects, these frictions can be considered quite normal and understandable as the two countries hold different values and priorities as a result of their different histories and cultures. At the same time, it is essential that the two countries also do not allow their disagreements to damage the overall potential for expanded bilateral engagement and cooperation; this necessarily will require the two countries to use wisdom and common sense to negotiate and explore mutually acceptable solutions to pressing problems so that they are not allowed to spiral out of control.

Towards this end, and to promote deeper and more extensive exchanges and cooperation between the two countries in the field of S&T, following some preliminary efforts in 2008 and 2009, in October 2010 the U.S. and China formally inaugurated an ongoing 'innovation dialogue' that is held annually in alternate years in Beijing and Washington D.C. The dialogue involves the joint participation of both governments as well as representatives from industry and academia. The dialogue serves as a platform for frank, in-depth discussions regarding issues of mutual concern regarding innovation-related topics. A key aspect of the innovation dialogue is the inclusion of a joint group of 'innovation and S&T policy experts' that, broadly defined, meet and exchange views regarding specific problems and challenges in U.S.-China S&T relations. The so-called 'expert group' is also responsible for conducting in-depth policy-related research and analysis as well as offering recommendations for ameliorating obstacles to future U.S.-China cooperation. So far, the innovation dialogue has achieved fruitful results; it has become one of the new mechanisms for enhancing the quality and depth of U.S.-China S&T exchanges and cooperation. Moreover, as part of the SED, it has helped ensure that S&T issues are integrated at the highest levels into the larger fabric of the overall bilateral political relationship. And, while the initial outcomes of the innovation dialogue so far have been somewhat limited up to now, it is clear that this type of mechanism will become an increasingly significant part of the bilateral relationship as collaborative research in basic, applied and commercially oriented fields continues to grow and deepen over the coming years.

29 Ministry of Science and Technology of China, "U.S.-China Clean Energy Research Center 2011 Annual Report", 2011.

Through this channel and other new forms of exchanges, both sides have enhanced their mutual understanding of each other's innovation policies and practices, reduced areas of difference and increased consensus, albeit gradually. Yet, at the same time, in a number of areas, there remain fundamental, seemingly intractable differences in understanding and perspective. From the U.S. point of view, the main issues[30] include:

- Concerns that China's innovation policies are dominated by too much formal and informal government intervention. There is an ever-present anxiety among many American policymakers and corporate officials about Chinese policies – past and present – that promote greater indigenous innovation through preferred government procurement and related regulations essentially discriminate against foreign enterprises.
- China's government lacks sufficient commitment to the enforcement of IP rights protection and the P.R.C. government is using unfair pressures to 'force' foreign enterprises to transfer technology as a price for market access.
- Steadily growing concerns across government, industry and even academia about cyber-security violations and industrial espionage.

From China's perspective, the main issues include:

- The U.S. remains unwilling to reduce many of the remaining Cold War-linked restrictions on high technology exports to China. Chinese officials believe that the U.S. should fulfill its promise to lift current controls on high-tech exports to China as soon as possible[31].
- Existing 'controls' on investments by Chinese enterprises in the U.S. economy are highly discriminatory and are often political rather than substantive in nature[32].
- The fields and content of U.S-China S&T cooperation should be made broader and deeper, for example, cooperation in space technology.

Nevertheless, despite such concerns from both sides, U.S.-China cooperation in S&T seems to have remained as one of the hallmarks and anchors of the U.S.-China relationship. During the third round of the SED held in 2011, for example, the two sides agreed to expand cooperation in selected fields, including energy, environment, transportation, climate change and S&T. The two governments signed the "Comprehensive Framework for Promoting Strong, Sustainable and Balanced Growth & Economic Cooperation". During the SED, the U.S. and China reached several specific agreements regarding energy, agreeing to work under the existing frameworks, including the "China-U.S. Energy Cooperation Projects", "China-U.S. Renewable Energy Partnership" and "China-U.S. Shale Gas Cooperation Memorandum of Understanding". They also committed to carry out cooperation regarding the smart grid, the development of large-scale wind power, natural gas distributed energy, shale gas and aviation biofuels, etc. and also agreed to share energy regulatory experiences and related practical information. From the list of 48 key outcomes announced by both sides from the SED, 15 are directly related to energy cooperation; the two sides also signed agreements for six new green partnerships.

Policy Recommendations

1 U.S.-China cooperation in S&T has continued to play an important role in the U.S.-China bilateral relationship during the past several decades. Cooperation and collaboration in the S&T sphere

30 US concerns about indigenous innovation policies, IPR protection and cyber security are addressed in more detail in Part II, Chapter 14.
31 High tech export control issues are addressed in more detail in Part II, Chapter 9.
32 China's concerns about possible politicized and unfair treatment of Chinese investments in the US are discussed in more detail in Part II, Chapter 13.

remains one of the cornerstones of overall cooperation between the two countries. Given present trends regarding the globalization of innovation and cross-border R&D growth, U.S.-China S&T cooperation promises to play a unique and important shaping role, with respect to the onset of a new foundation for sustaining the U.S.-China bilateral partnership. Accordingly, both governments and their senior leaders need to recognize the actual and potential strategic importance of deepening U.S.-China S&T cooperation.

2 The U.S. and China remain highly complementary in terms of their respective S&T capabilities. The existing complementary mix of skills and available resources holds great potential for expanding the breadth and depth of U.S.-China cooperation in S&T. At the same time, there are some serious differences and frictions between the U.S. and China in the area of S&T cooperation that simply cannot be glossed over. Both sides should pay attention to and take positive measures to strengthen serious communication and understanding, seek common ground while reserving differences and strive for cooperation that is less hierarchical and more oriented in the win-win direction. Even though this may seem like a lofty goal, it reflects the new realities of China's rise and the changing complexion of the bilateral relationship in all areas of importance.

3 The U.S. and China should promote new forms and patterns of scientific and technological cooperation in key areas. These new approaches to cooperation need to be based on a shared understanding of the characteristics of various industries, greater emphasis on market-oriented models and a greater willingness to take advantage of America's established and recognized strengths in marketing, distribution and promotion, and China's availability of investment resources. Strong emphasis should continue to be given to the solid relationships that already have been built in the field of agricultural S&T, clean energy and environmental management; enhanced importance should be given to such fields as healthcare, life sciences and medicine, where both nations face many challenges and could benefit from more knowledge sharing.

4 There is great potential for U.S.-China cooperation in space exploration. The U.S. Space Shuttle has been retired from service since it accomplished its final flight in July 2011. At present, Russia is the only participating country in the International Space Station (ISS) program that is capable of transporting U.S. astronauts to and from the Low Earth Orbit. As some experts have stressed recently[33], it may be more efficient for the U.S. to maximize its utilization of the ISS given that the assembly of the station is now complete. To achieve a higher utilization rate, the U.S. could consider cooperating with China in order to gain additional access to the station. In this regard, the U.S. may wish to consider inviting China to join the ISS program, and offering assistance to China to adapt its Shenzhou Spacecraft to become compatible with the station.

We share the view of George Abbey and Leroy Chiao[34] that "a partnership with China could be developed along the same lines as was done with integrating the Russia space program into the ISS partnership". Under this cooperation model, no U.S. militarily sensitive technology of the U.S. would be transferred to China. China's growing space budget supported by its rapid economic growth allows it to not only fully fund its own space programs, but also to bear a larger share of the expenditure involved in joint projects with the U.S. The U.S. is therefore expected to incur only minimal monetary and implicit costs in cooperating with China in space exploration.

33 George W.S. Abbey and Leroy Chiao, "Time for the U.S. to Partner with China in Space?", December 2012, http://news.discovery.com/space/private-spaceflight/opinion-nasa-partner-china-politics-spaceflight-gap-121127.htm
34 Ibid.

A successful joint U.S.-China manned space flight could have great symbolic value and political significance in both countries. Closer bilateral cooperation in space could enhance mutual trust between the two countries by improving the transparency of each other's space policies and goals. It also would allow further leverage to each other's apparent technological complementarities as noted throughout this article.

What space program partners of the U.S. and space experts say

Dr Joan Johnson-Freese

a professor of national security affairs at the Naval War College and the author of many books and journal articles on space programs and cooperation, shared her views with CNN on 20 June 2012.

"The United States largely knows what space technology China possesses, but it doesn't know what China's intentions are. The United States should try to better understand China's space goals.

However, NASA is prohibited by law from working with China. This makes no sense. If one believes that China and the United States are not inherently enemies, then working together on space projects – with technology transfer controls – will benefit both countries. If one believes that China is inherently a threat to the United States, then the adage 'keep your friends close and your enemies closer' comes to mind.

The script for U.S.-China relations – and space relations in particular – is constantly evolving. The United States can influence the direction, but only if we engage and persuade the Chinese to engage with the U.S. It's one way of preventing a scenario of a galactic Wild West in which China has become the world's leader in space."

At the ISS Heads of Agencies Meeting on 1 March 2012 in Canada, two leaders of space agencies commented on the cooperation with China in space exploration:

Vladimir Popovkin, General Director of the Russian Federal Space Agency, believed that China will collaborate with the five current partners – the United States, Canada, Japan, Russia and the European Space Agency – in the coming future. "We are not a closed club; our doors are wide open", he said.

Jean-Jacques Dordain, Director-General of the European Space Agency said, "I am in favor of seeing how we can work together with China. It will take some steps, but it will come, I am sure. … This is not a closed partnership, it is an open partnership and anyone who can help support this partnership is more than welcome," he added.

Sources:
Joan Johnson-Freese, "Will China overtake America in space?", CNN, June 2012 http://edition.cnn.com/2012/06/20/opinion/freese-china-space

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http://thechronicleherald.ca/canada/69141-space-station-not-closed-club-would-welcome-china-india

5 The U.S. and China should continue to utilize and improve the consultation mechanisms built into the U.S.-China Joint Commission on Science and Technology Cooperation; continue to support, deepen and institutionalize the U.S.-China innovation dialogue through expanded high-level bilateral exchanges and communication; provide greater exchanges of experts in the field of S&T policy and development strategy; and engage in a deeper and broader array of interactions regarding the dynamics of emerging industries. All of these actions will help guide U.S.-China S&T cooperation in directions and fields that explicitly benefit not only each other, but also the rest of the world.

6 The U.S. and China should initiate a dialogue to examine their common interests regarding globalization of the pool of high-end talent, further encourage the exchange of visits by scientists – junior and senior – from the two countries, carry out truly collaborative joint research projects and identify new ways to work together to train the next generation of S&T personnel and teachers. The importance of exchanging ideas about 'the global talent pool' promises to become more pressing in view of proposed changes in U.S. immigration policies and regulations.

7 The U.S. and China should further strengthen exchanges and dialogue regarding IP protection and information security, establish more effective communication channels for exchange of information and data, and strengthen the strategic foundations of mutual trust by exhibiting a willingness to take on sensitive issues – for example, on cyber security – that potentially threaten the integrity of the bilateral relationship. In response to ample progress on this front, the U.S. and China should enter into an explicit dialogue regarding the potential reduction of high-tech export controls and the removal of unwarranted trade barriers. In this regard, the U.S. needs to acknowledge the broad implications of China's rise as a global power, while China must understand that with greater power comes increased responsibilities and obligations on a regional and global level.

8 The U.S. and China should consider establishing bi-annual bilateral S&T expos in each country, intensify knowledge about the positive outcomes of U.S.-China S&T cooperation, and work together more closely to promote public understanding of the S&T achievements taking place in the U.S. and China. The two countries also need to identify mechanisms to ensure the emergence of a new generation of China S&T policy experts on the U.S. side and U.S. S&T policy experts on the Chinese side. Regular meetings and exchanges among such 'expert groups' should become a regular feature of their bilateral engagement.

9 Finally, the U.S. and China need to recognize that as they grow the level and extent of their S&T cooperation, the increase in the number of touch points between the two countries will need to be accompanied by a concomitant focus on quality and effective project management. In some cases, some exchanges between the U.S. and China have proven to be less than rewarding or successful because of mismanaged expectations, cross-cultural misunderstandings, and excessive government red-tape or communication problems. Recent efforts at cooperation in geology, mapping and seismic evaluation, for example, have run into an assortment of snags that have left both sides wanting, especially in terms of access and the overall productivity of their fieldwork. Both countries need to do a better job in putting concerns and issues – security or otherwise – on the table before specific exchanges begin so that neither side will be disappointed in the results of their collaboration. Fortunately, these types of problems have not dominated the overall S&T relationship, but their sporadic presence is a bothersome reminder that adequate preparation must precede all projects and programs.

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