The Impact of Science and Technology Policies on Rapid Economic Development in China

Dongmin Chen, Shilin Zheng, and Lei Guo, Peking University

Thirty years of ongoing economic reforms in China has led to an uninterrupted annual economic growth rate of more than 9% on average,[1] an astonishing accomplishment. In 2010 China surpassed Japan in terms of GDP and became the second largest economy in the world. In 2014 China's GDP reached US$10 trillion dollars: it is now one of only two countries in the world to have attained this scale—the other is the United States of America (USA).[2] Policy reform and innovation have been important drivers of China's remarkable achievement.[3] Since 1978 China has implemented a series of large-scale science and technology (S&T) reforms that have accelerated progress in higher education and research and development (R&D). The 2008 global financial crisis disrupted the high growth rate of China's manufacturing-based economy, which adapts or imitates traditional technologies from developed economies. As a result of this crisis, China was pressed to make structural economic reforms that focused on building up domestic innovation infrastructure and the competitiveness of domestic research institutions. These policies have become key factors in influencing the country's continuing economic development. In 2014 the Global Innovation Index (GII) ranked China at 29th place worldwide, 1st among upper-middle-income nations and 7th in the South East Asia and Oceania regions. China also leads substantially in innovation among the BRICS nations (Brazil, Russian Federation, India, China, and South Africa). China's most notable achievement in the GII is in the Knowledge and technology outputs pillar, in which it ranked 2nd in 2014; this led to its 2nd place in the Innovation Efficiency Ratio in that year. This chapter provides an overview and analysis of the evolution of China's key S&T policies and their impact over the past three decades. It also outlines a new phase of key policy change taking place today that could have major effects in the coming decade.

Four phases of China's S&T policy evolution

In the late 1970s China implemented a series of S&T policies to boost the country's economy in relation to the rest of the world. Since then, its S&T policies have evolved to become vital drivers of progress for both research and the economy.

The experimental phase (1978–85)

In early 1980s, China's economic foundation was weak and its level of S&T research was far behind that of developed nations. It became clear that the Soviet model for S&T research, which it had adopted in the 1960s, had serious drawbacks and had led to a severe disconnect between research and industry. Initial policy reform, therefore, focused on spin-offs and partial privatization of selected parts of public research institutions that were commercially viable. This separation initially alleviated some of the financial burden of the holding institutions; later these privatized entities became substantial assets. Although they were few in number, some of the most successful technology companies in China today were formed during this period. They include the computer products and services company Lenovo (formerly Legend computer), a spin-off from the Computing Institute of the Academy of Sciences; and the conglomerate Founder Group, a spin-off from Peking University based on a digital Asian font typesetting technology. The initial phase of reform took a bottom-up approach because at that time national S&T funding was still very limited. At the national level, important initiatives such as the Key National Research Projects (1984), the Key National Laboratories, and others were launched to focus the limited available funding on research groups that exhibited better performance.[4]

The systemic reform phase (1985–95)

Top-down nationwide system reforms did not take place until 1985, when the central government issued the Science and Technology System Reform Act. The primary objective of this Act was to bridge the gap between research institutions and relevant industries. By emphasizing competitiveness and other connections to the market, the Act aimed to gradually strengthen the economic impact of S&T funding. As a result of this Act, a number of reforms took effect. The most significant included the establishment of the National Natural Science Foundation of China, which is intended to promote and finance basic and applied research,[5] along with a number of new initiatives supporting applied and translation research such as the 863 Program (1986), the Spark Plan (1986), the Torch Plan (1988), and the Shenzhen Stock Exchange for small and medium-sized enterprises (1990), which all sought to improve the prospects of commercialization.[6]

To improve the country's higher education system and enhance the link between higher education and social development, in 1993 the government instated the 211 Project as part of its long-term strategies for national economic and social development. A special budget was dedicated to a group of leading universities selected from each province and from major cities such as Beijing. This budget was enacted in the country's 9th Five-Year National Budget Plan, and was fully implemented in 1995. An important talent programme—the Hundred Talents Program of the Chinese Academy of Sciences, which offers positions to qualified applicants with an international doctoral degree—was also introduced during this period to encourage overseas Chinese scholars to return to China and take up key teaching and research positions.[7]

The deepening reform phase (1996–2006)

The 9th Five-Year National Budget Plan, the Outline of the 2010 National Target, and a series of resolutions officially kicked off a period of deepening of system reform in S&T development. A fundamental national strategy was officially established with the aim of 'rejuvenating the nation's economy with science and education.' In 1996 China passed the Act of Promoting Commercialization of S&T Discoveries and Inventions. Together these new policies focused on three areas: shifting the drivers of innovation from public research organizations to industrial sectors; improving the R&D and innovation capacity of industrial sectors; and improving the efficiency of the commercialization of academic outputs.

During this period, changes in the national innovation infrastructure encompassed four key measures. These measures were the launch of the 985 Initiative, intended to expand the 211 Project to include key technology and engineering universities for the national advanced education development fund as a way to foster the development of world-class Chinese universities; the implementation of the Knowledge Innovation initiative in the Chinese Academy of Sciences to raise the research levels of public institutions; the establishment of large-scale R&D funding for basic research with initiatives such as the 973 Program; and the introduction of the Yangzi River Scholars Program, which significantly increases professors' wages to attract talented researchers and professors to Chinese Universities.[8]

Long-term plan and policy optimization (2006–14)

A Medium- and Long-Term National S&T Development Plan for 2006–2020 (the 2006 National Plan) was issued in 2006. The 2006 National Plan outlines guidelines for S&T development: nurturing independent innovation, fostering the ability to leapfrog in key technology areas, building major infrastructure, and developing future global leadership. The plan emphasizes achieving sustainable economic growth, seeking innovation-driven growth strategies, and enhancing independent innovation capacity. During this period the government's focus was the optimization of the effectiveness of the policy and the management of its implementation. Previously issued policies and regulations that had lacked coordination needed to be consolidated into sets of coherent policies. Policy objectives shifted from promoting R&D to building an innovation ecosystem. Those one-fits-all policies had to be tailored to address more specific goals to be effective.

To further push the mobility of innovative talent, particularly in critical S&T fields, a very effective Thousand Talents Recruitment Program was launched by the central government in 2011. So far this programme has drawn more than 2,000 overseas Chinese scholars and leading industrial innovators back to China.

In 2012 China set the goal of being a 'top innovative nation' by 2020. The 18th Communist Party National Congress held at the end of 2012 established 'innovation-driven growth strategy' as a national development strategy. It called for setting clear targets, improving entrepreneurship, making industry the main driver behind innovation, and establishing market-oriented mechanisms to facilitate collaborative technology transfer from academics to the industrial sectors. Together, these changes should propel China's global competitiveness in innovation and ensure its long-term sustainable development.[9]

Outcomes and analysis of S&T reform

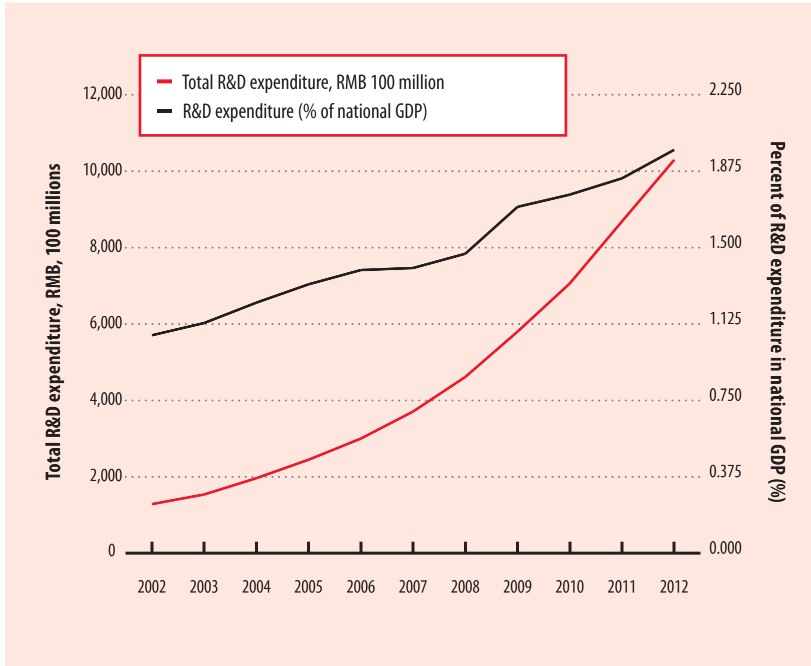
The wide range of S&T policies implemented and adjusted in the past three decades in China has had a direct impact on the outcomes that apply to innovation. From 2002 to 2012, China's GDP more than quadrupled, leaping from US$2 trillion to US$8.7 trillion. The data reveal that these policies have effectively advanced the development of an innovation ecosystem; they have also brought about an educated workforce of significant size, laying a solid foundation for the future development of innovation capacity in the country.

The next sections present basic data illustrating China's S&T development in this decade in four areas: R&D investment; the results of innovation—that is, patents, products, and research publications; science education; and the cultivation of R&D talent.

S&T and R&D investment

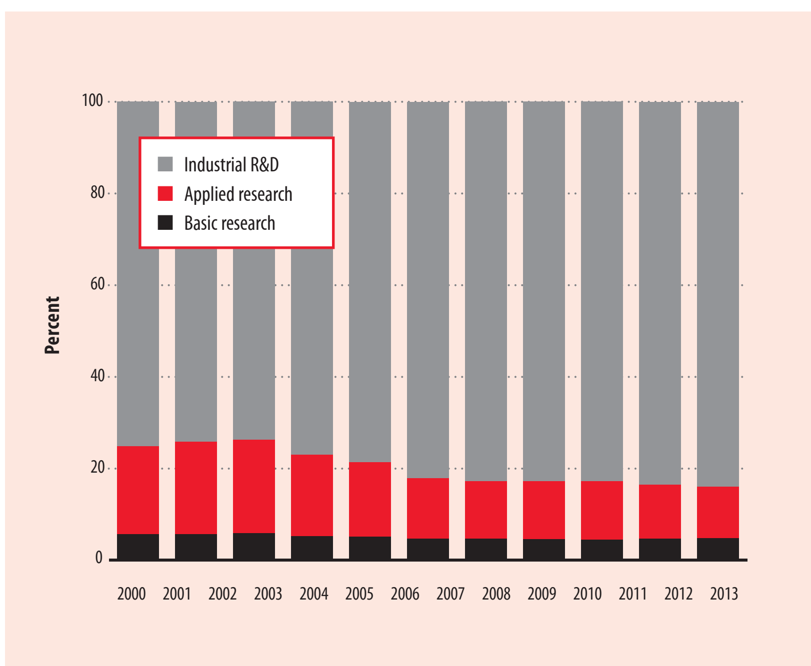
As shown in Figure 1, total R&D investment in China increased from about 1% of GDP in 2002 to 2% of GDP in 2012.[10] The share of local government fiscal expenditure on S&T relative to the central government fiscal expenditure on S&T jumped from approximately 40% of total government fiscal expenditure on S&T before 2007 to approximately 50% since 2007.[11] This increase is strongly correlated with the issuance of the 2006 National Plan. Figure 2 shows that the percentage of R&D investment increased from 2002 to 2012, although investment in basic and applied research has not kept pace. R&D investment by the industrial sector increased steadily from 70% of total investment in 2002 to 80% in 2012.

Figure 1: Total R&D investment, 2002–12



Source: National Bureau of Statistics of China, 2013a.

Figure 2: Distribution of S&T investment, 2002–12



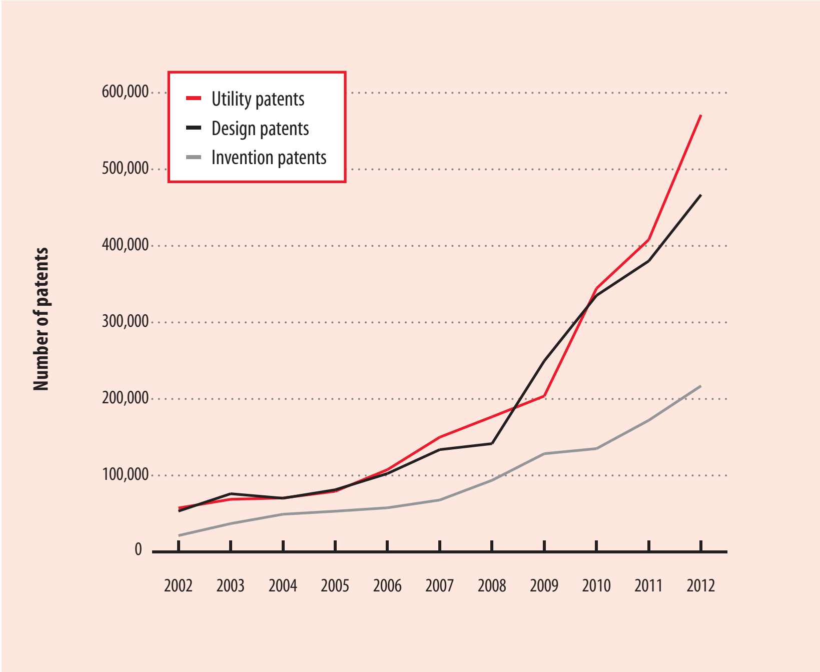
Source: National Bureau of Statistics of China, 2013b.

Innovation results: Patents, products, and research publications

Domestic patent applications have grown rapidly, with an average rate of approximately 17.5% in recent years. Since 2012 China has become 1st in the GII indicator for the number of total domestic patent applications; it has also been 1st in the GII indicator for domestic resident utility model applications for all years from 2011 through 2014. However, based on national data, the growth of international patent applications appears to be slowing in comparison to the very rapid growth of domestic patent applications. Within the domestic applications, the issued invention patents grew more slowly than issued utility models patents and designs patents (see Figure 3). Between 2002 and 2012 technology product output (proxied by revenue from new products; see Figure 4), increased rapidly, especially after 2006. This increase demonstrates that the Chinese government's innovation policies were successful in attracting organizations to invest in R&D and helping enterprises to be more successful in terms of innovation.

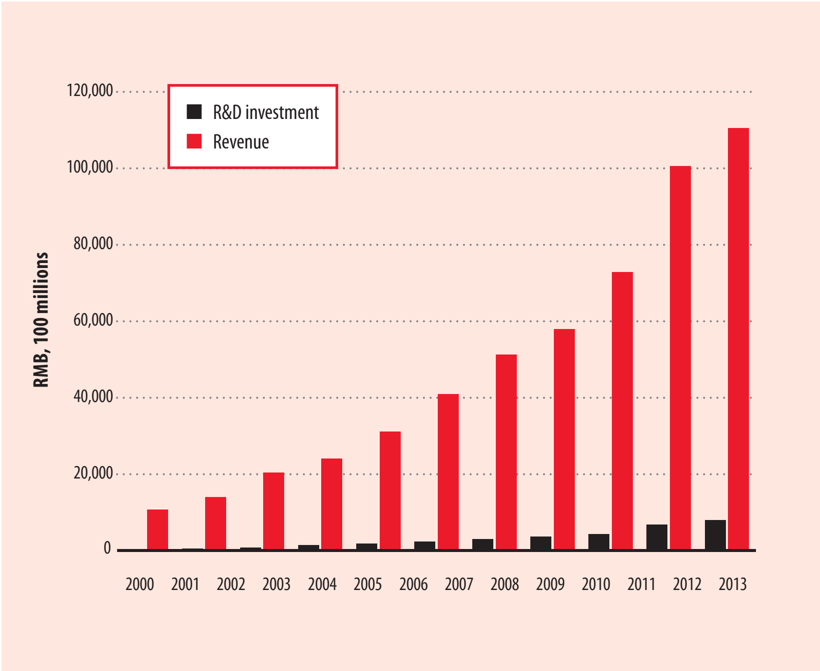
Figure 5 shows that Chinese research publications have made huge increases from 2000 to 2011 according to the three key international indexes—the Science Citation Index (SCI), the Engineering Index (EI), and the Conference Proceedings Citations Index-Science (CPCI-S). The corresponding average annual growth rates are 16.6%, 22.9%, and 21.8%, respectively. In 2000, China ranked only 8th, 3rd, and 8th worldwide in the SCI, the EI, and the CPCI-S, respectively. Since 2007, these worldwide rankings have gone up to 2nd, 1st, and 2nd place, respectively. This demonstrates that both the 211 Project of 1993 and the 985 Initiative of 1998, which aimed to boost higher education

Figure 3: Patents issued, 2002–12



Source: National Bureau of Statistics of China, 2013b.

Figure 4: R&D investment and revenue from new products, 2002–12



Source: National Bureau of Statistics of China, 2013b.

and establish the Chinese Natural Science Foundation and other research establishments, have made a great impact on China's research publications.

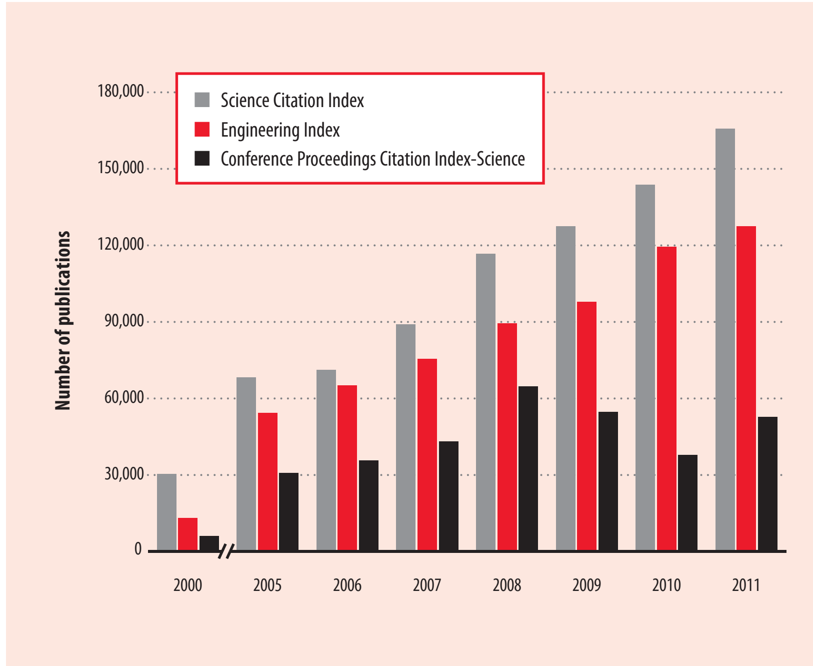
Science education

The successful development of science and technology in China cannot be separated from the development of education and the cultivation of a highly skilled workforce. The reform puts an intense emphasis on education and is making a huge attempt to develop top-quality education and to increase the ratio of high school graduates who are enrolled in colleges and universities. The number of college and university graduates in the sciences increased from 1,337,300 students in 2002 to 6,081,600 in 2012 (Figure 6)—an average annual increase rate of 16.4%. The number of Master and PhD graduates increased from 80,800 in 2002 to 486,500 in 2012, an average annual increase rate of 19.7%. The vast talent cultivated by the strong scientific education system continuously offers a highly skilled, educated workforce for the marketplace to support the rapid build-up of China's innovation system.

Cultivation of an R&D workforce

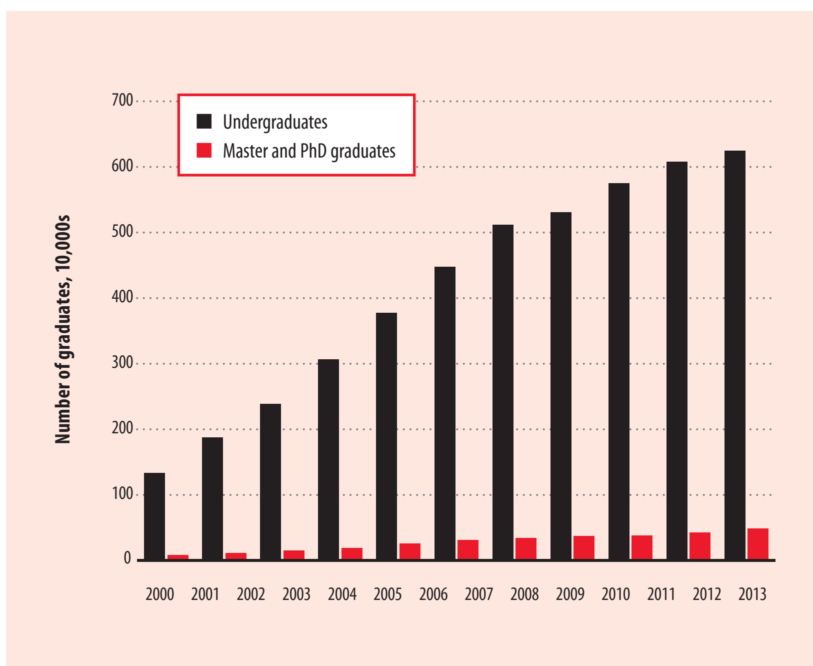
China's S&T policies place great value on S&T talent mobility. The Thousand Talents Program and a series of other talent programmes have greatly added to China's high-end talent pool, especially in the most competitive fields. A number of important breakthroughs can be attributed to those who have returned to China from abroad. China's focus on education has led to a rapid increase in the number of R&D personnel (the GII indicator for researchers in headcounts per million population increased from

Figure 5: Number of Chinese science and technology publications taken by three key international indexes, 2002–12



Source: National Bureau of Statistics of China, 2013b.

Figure 6: Graduates in science, 2002–12



Source: National Bureau of Statistics of China, 2013b.

1.1 million in 2009 to 1.5 million in 2012), as well as their quality and skill. Since 2004 China's R&D full-time equivalent personnel grew at a rate of 10% or higher, and by 2012 it had already reached a total of 3.3 million people.[12]

What other countries can learn from China

Since their beginning in the 1980s, China's evolving S&T policies and its economic reforms have had a profound effect on the outcome of innovation in the country, especially from 2002 to 2012. By considering the quantitative analysis made available by the GII, the following positive observations can be drawn: First, the shift from a bottom-up to a top-down approach has worked well for a developing economy that began with limited national resources.

Second, the increase in R&D investment went hand in hand with a large increase in GDP, as evidenced by China's improvement in the GII indicator on gross expenditure on R&D, which progressed from 25th place in 2012 to 21st in 2013, and finally to 19th in 2014. Most notably, following the launch of the 2006 National Plan, Chinese R&D investment clearly stepped up and the rate of local government investment in R&D surpassed the rate of investment made by the central government. Moreover, the positive market response encouraged the industrial sector to steadily increase R&D investment, as seen by the improvement in GII variable GERD financed by business, which grew from 73.9% in 2011 to 74.6% in 2014. However, investment in basic and applied research has not kept up with this pace, warranting serious concern.

The third observation is that the strategy of 'rejuvenating the nation's economy with science and education' has accelerated the development of China's top education system (evidenced by the GII variable QS university ranking, which improved from 36th in 2011 to 10th in 2014). The quantity of undergraduates and Master's graduates has clearly increased (seen by the GII variable on tertiary enrolment, which grew from 21.8% of gross enrolment in 2009 to 26.7% in 2012). Both the quality and quantity of researchers has greatly increased, and the rate at which researchers in basic sciences has increased has been comparatively higher than the rate of increase of researchers in other areas.

The fourth observation concerns the outputs of R&D research: the increase of patent applications in China and of utility patents has been rapid. This growth is demonstrated by the GII through its indicators domestic resident patent applications, which rose from 293,000 patents in 2010 to 704,000 patents in 2013; and domestic resident utility model applications, which rose from 407,000 applications in 2010 to 885,000 in 2013. In addition, science and technology publications by Chinese researchers have enjoyed a high intake worldwide by the SCI, the EI, and other international indices, although the percentage of top-quality papers remains low (seen in the GII through scientific and technical articles, ranked 40th in 2011 dropped to 56th in 2014; and citable documents H index, ranked 16th in 2014).

What China can learn from other countries

Although China has made remarkable achievements in R&D investment and S&T outputs, quite a large gap still exists between China and developed nations in terms of investments in basic research, high-value inventions, and high-impact research, which are all essential for entering the high-income category of nations. Indeed, the 2014 GII placed China 2nd in the Knowledge and technology outputs pillar, close to or even overtaking some high-income nations. However, Creative outputs (ranked 59th in 2014), Market sophistication (concerned with credit system and openness, ranked 54th in 2014), and Institutions (concerned with the regulatory and legal system, ranked 114th in 2014) are three pillars that have dragged down China's overall GII competiveness when compared with top-ranking countries. China has set a national target of becoming a leading innovative country by 2020. Achieving this target depends on continuing policy reform to further improve a balanced relationship between the government and market forces; to establish a more comprehensive innovation ecosystem; to nurture a legal and regulatory system that encourages investment in innovation and entrepreneurship by all sectors; and to foster open and fair competition among private, state-owned, and foreign enterprises.[13] To meet this goal, besides boosting investment in research and commercialization activities, China can look towards reforms undertaken by other countries at the same level of development to address issues in legal and regulatory systems, encourage market forces, and foster competition among all stakeholders.

The latest reforms

During the National Innovation Conference held in 2012, the Chinese government clearly acknowledged the need to improve the above-mentioned areas.[14] Since the transition of the present government during the 18th Communist Party Congress, China has begun yet another round of policy reforms, five of which are noted here. First, an amendment to the National Act for Promoting Technology Transfer has been put forward; this may become China's own Bayh-Dole Act (also known as the US Patent and Trademark Law Amendments Act), giving universities and public institution's the autonomous right to license the patents generated from central government R&D funding. It further ensures that inventors will share in a greater percentage of the proceeds. A pilot programme to test this new law has already begun in 11 universities, and it is predicted that it will not be long before it is enacted by the next session of the Chinese People's Congress. Second, in January 2015 the Chinese government issued the 2014–2020 Action Plan on the Implementation of National Intellectual Property Strategy. The plan aims to ease market processes for transactions pertaining to intellectual properties, including declassifying classified patents for civilian use and providing funding support to seed companies that specialize in intellectual property transaction services. Third, to address efficiency in S&T funding, the Chinese government has overhauled the entire S&T funding process, which will be replaced by a new process with a greater accountability to the stakeholders. Fourth, China has launched a special stock market (the National Equity Exchange and Quotations) to allow technology start-up companies, which are not yet profitable, to have more avenues to raise development capital. Furthermore, rules and regulations are simplified to encourage mergers and acquisitions. And fifth, in March 2015 the Chinese government published *A Guideline for the Development of Public Incubation Space to Promote Grassroots Entrepreneurship*.[15] This guide encourages the participation of multilevel capital markets, including crowdfunding.

The new set of policies being implemented today should help to address many of the country's challenging issues in the coming decade and have a positive impact on China's ranking in future GIIs.

Notes

1 World Bank statistics show that since 1978, China's GDP growth rate is 9.83% on average (see the World Bank's World Development Indicators database, http://databank.shihang.org/data//reports.aspx?source=2&country=CHN&series=&period=).

2 China's GDP of China reached RMB 63.64 trillion (US$10.36 trillion) in 2014. The data can be found from the central government's work report of 2015, available at http://www.guancha.cn/politics/2015_03_17_312511.shtml (in Chinese).

3 Chinese officials have long been aware of the importance of S&T. Deng Xiaoping stated in 1988, when meeting with President Gustav Husak of Czechoslovakia, 'In my opinion, science and technology is the most important productive force.' Details of the speech can be found at http://news.xilu.com/2009/0903/news_112_13463.html (in Chinese).

4 For more information on Chinese State Key Laboratories, see https://en.wikipedia.org/wiki/State_Key_Laboratories.

5 Details about the National Natural Science Foundation of China are available at http://www.nsfc.gov.cn/publish/portal1/.

6 Details of the Spark Plan can be found at Cao, 2006, and at http://in.china-embassy.org/eng/szyss/jm/zhongguonongye/agricultureplanning/t143140.htm, (at http://baike.baidu.com/view/57377.htm in Chinese); details of the 863 Program at https://en.wikipedia.org/wiki/863_Program (http://baike.baidu.com/view/4785616.htm in Chinese); of the Torch Plan at http://www.chinatorch.gov.cn/english/index.shtml; and of the Shenzhen Stock Exchange for small and medium-sized enterprises at http://baike.baidu.com/link?url=PpsCaaGhLeRFCF0JtxxJy3Xw1jqUugdN5Pv9vlQ1mwvJuGHe7Fr1QlCFoxel12x2qWi1LKqFsfHTQgEwktKF9_ (in Chinese).

7 For information on the Hundred Talents Program, see http://english.ucas.ac.cn/JoinUs/Pages/TheHundredTalentsProgram.aspx.

8 These plans succeed in helping Chinese colleges and universities attract many overseas talents, promoting the progress of Chinese higher education and levels of scientific research.

9 *The Reform and Opening Up of Chinese S&T in the Past 30 Years*, a book by the former minister of the S&T department, Wan Gang, gives a detailed description of these policies and their influence.

10 These data are from CNKI (China National Knowledge Infrastructure), the largest Chinese database, which contains abundant data for almost every field in science and social science. CNKI is available at http://www.cnki.net/ (in Chinese).

11 Chinese R&D investment includes two parts: industrial sector funding and government funding. Government funding can be further divided into central government funding and local government funding.

12 National Bureau of Statistics of China, 2013b.

13 More details are discussed in People's Publishing House, 2012.

14 See speeches by General Secretary Hu Jingtao, Prime Minister Wen Jiabao, and Deputy Prime Minister Liu Yandong in the 2012 National Innovation Conference. The full content of these is not available online, but a summary can be found at http://www.gov.cn/ldhd/2012-07/07/content_2178574.htm (in Chinese).

15 The Chinese government attaches great importance to entrepreneurship now. Prime Minister Li Keqiang has frequently granted interviews to representatives of successful entrepreneurs seeking to improve conditions for entrepreneurship in the country.

References

Cao, Y. 2006. *The Exploration and Practice of Spark Plan for Past 20 Years.* Beijing: China's Agricultural Science and Technology Press.

Lin, Y. 2014. *The Miracle of China.* Shanghai: Due Press.

National Bureau of Statistics of China. 2013a. *China Statistical Yearbook 2013.* Beijing: China Statistics Press. Available at http://www.stats.gov.cn/tjsj/ndsj/2013/indexeh.htm.

———. 2013b. *China Statistical Yearbook on Science and Technology.* Beijing: China Statistics Press.

People's Publishing House. 2012. *Speed Up the Construction of National Innovation System by Deepening the Reform of Science and Technology System.* Beijing: People's Publishing House.

The People's Republic of China. 2015. *A Guideline for the Development of Public Incubation Space to Promote Grassroots Entrepreneurship.* Official report.

The People's Republic of China, State Council. 2006. *National Outline for Medium and Long Term Science and Technology Development (2006–2020).* Official report.

Wan, G. 2008. *The Reform and Opening Up of Chinese S&T in the Past 30 Years.* Official report.