> *The innovation risk of enterprises needs to be shared via incentive policies and the development of public infrastructure to support innovation.*
>
> Mu Rongping

18 · China

Mu Rongping

INTRODUCTION

China has made great strides in system reform and economic development over the past decade. The world's fastest-growing large economy, it will overtake Japan by the end of 2010 to become the world's second-biggest economy in terms of GDP[1].

The country has emerged more or less unscathed from the global economic recession triggered by the sub-prime crisis in the USA in 2008. After an initial slump in employment caused by falling demand for exports to Europe and the USA, China's economy bounced back in 2009, growing by 8.7% (IMF, 2010). The key driver of this growth is government-led investment. For example, the government has implemented a plan for injecting an additional 4 trillion Yuan (*circa* US$ 590 billion) into the economy over a two-year period. According to this plan, the central government is investing 1.18 trillion Yuan to leverage local governments and private firms to spend more than 2.82 trillion Yuan. Another government plan aims to restructure and invigorate ten key industries: automobile, iron and steel, textiles, equipment manufacturing, shipbuilding, petrochemicals, light industry, electronic information, non-ferrous metal and logistics. The central government's investment rose from 420.5 billion Yuan in the previous year's budget to 924.3 billion Yuan (*circa* US$ 62.8 billion) in 2009. Of this, 16% was earmarked for innovation, restructuring, energy-saving, reducing greenhouse gas emissions and environmental protection. This not only effectively compensated for the shortfall created by shrinking external demand but also strengthened weak links and laid a solid foundation for long-term socio-economic development (Wen Jiabao, 2010).

The government has given environmental protection high priority in the *Tenth* (2001–2005) and *Eleventh Five-Year Plans* (2006–2010). It has imposed the mandatory objective of reducing energy consumption per unit of GDP by 20% and emissions of major pollutants by 10% by the end of the *Eleventh Five-Year Plan* in 2010, in order to reverse the trend of ecological and environmental deterioration over the past two decades. In April 2010, Chinese Premier Wen Jiabao announced plans to adopt a binding target for cutting carbon dioxide emissions (Box 1). Local government leaders and entrepreneurs are expected to assume a greater role than before in achieving these targets and will be evaluated for their performance in saving energy and reaching emission-reduction targets.

Over the past decade, China has not only multiplied gross domestic expenditure on R&D (GERD) by a factor of six but also improved its capacity for generating intellectual property rights (IPRs) via scientific papers and patents. Today, only the USA publishes more scientific articles (*see page* 10). The *Eleventh Five-Year Plan* for capacity-building in innovation foresees the rapid development of infrastructure to implement the knowledge innovation programme and the programme for science and technology (S&T) platforms: 12 megafacilities are to be established by 2010, as well as about 30 national science centres and national laboratories[2] and 300 national key laboratories.

In 2005, the government issued the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development* (2006–2020), which proposed that China become an innovation-driven country by 2020 (State Council, 2006). The government then issued a series of supportive policies to encourage endogenous innovation, as well as 76 detailed policy documents for implementing these supportive policies by the end of 2008. This series of policies has had a great impact on innovation in China and especially on the innovative capacity of enterprises. It shall thus be discussed in detail in the following section.

China's goal of becoming an innovation-driven country by 2020 is a highly ambitious one. Today, the R&D intensity of high-tech industry remains much lower in China than in developed countries. China faces daunting challenges in narrowing this innovation gap, not least of which will be to find the right balance between economic development and capacity-building in science, technology and innovation (STI).

Shanghai
Synchrotron
Radiation Facility

Photo:
© Shanghai
Institute of
Applied Physics

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[1] China ranks third in terms of annual output measured in US dollars but, in terms of purchasing power parity (PPP), it has been the world's second-largest economy for years.

[2] National laboratories are designed to conduct complex research and innovation, whereas national key laboratories usually focus on research in a specific discipline. Some national laboratories consist of several national key laboratories.

Box 1: Accelerating development and use of renewable energies

At the first meeting of the National Energy Commission in Beijing on 22 April 2010, Chinese Premier Wen Jiabao called for greater efforts to enhance the country's innovative capacity in energy technology to cope with rising domestic fuel demand and severe energy shortages. 'We must accelerate the development and use of renewable energies to ensure the country's energy security and better cope with climate change,' he said.

Wen went on to say that China ought to take measures to ensure that non-fossil fuels accounted for 15% of China's energy consumption by 2020. He also stated that the country would make it a binding target to cut carbon dioxide emissions per unit of GDP by 40–45% by 2020 from 2005 levels. 'The target will be incorporated into the country's long-term economic and social development plan,' he said.

The government set up the National Energy Commission in January 2010 to improve co-ordination of energy policy .The commission is responsible for drafting the national energy development plan, for reviewing energy security and major energy issues and for co-ordinating domestic energy development and international co-operation.

Source: Xinhua News Agency, 22 April 2010

A PLAN FOR MAKING CHINA INNOVATION-DRIVEN BY 2020

Priority areas for R&D to 2020

Experts have played an important role in the elaboration of the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development (2006–2020)*, the eighth in China's history. Once the 20 strategic issues had been selected in 2003 by the State Council and an expert consultation group composed of 20 scientists, more than 2 000 experts were invited to conduct studies on these topics. A broader consultation was also undertaken via e-mail, workshops and other means to enable people from all walks of life to contribute ideas. The *Outline* groups all technologies into five high-priority clusters:

- technologies in the fields of energy, water resources and environmental protection;
- information technology (IT), advanced materials and manufacturing;
- biotechnologies and their applications in the fields of agriculture, industry and human health;
- space and marine technology;
- basic sciences and frontier technology.

The *Outline* launches 16 megaprojects in S&T. These projects have been selected according to five basic principles. *Firstly*, each project should correspond to socio-economic needs, in order to cultivate strategic industries. *Secondly,* each project should focus on key common technologies that will have a profound impact on industrial competitiveness. *Thirdly,* each project should be capable of absorbing the main bottlenecks of socio-economic development. *Fourthly,* each should protect and enhance national security. *Last but not least,* each should be affordable for the Chinese government. In 2008, the government invested 3.6 billion Yuan in 8 of the 16 special megaprojects for civil S&T, corresponding to about 167 smaller projects. Thirteen of the 16 mega projects are listed in the *Outline*:

- core electronic devices, high-end generic chips and basic software;
- extra large-scale integrated circuit manufacturing technology and associated technology;
- next-generation broadband wireless mobile communication;
- advanced computerized numerical control machinery and basic manufacturing technology;
- large-scale oil and gas fields and coal-bed methane development;
- advanced large-scale pressurized water reactors and nuclear power plants with high-temperature, gas-cooled reactors;
- water pollution control and governance;
- cultivation of new varieties of genetically modified organisms;
- development of major new drugs;
- prevention and treatment of AIDS, viral hepatitis and other major infectious diseases;
- large aircraft;
- high-resolution Earth observation systems;
- human space flight and the Moon exploration programme.

In recent years, there have been a number of breakthroughs in priority areas for R&D. In 2003, China became the third country after Russia and the USA to send astronauts into space, for example, and there are plans to land a rover on the Moon by 2012. In information technology, a team at the University of Science and Technology of China built the world's first photonic telephone network in April 2009 (Box 2), six months before China's fastest supercomputer was released in Changsha (Box 3). Also of note is the completion of the Shanghai Synchrotron Radiation Facility in April 2009, the biggest scientific platform in China so far (Box 4).

Policies for building an innovation-driven nation

Since the adoption of the *Outline of the Medium- and Long-Term Plan for National Science and Technology Development*, the government has issued a series of innovation policies with a view to establishing an enterprise-centred national innovation system and making China an innovation-driven nation by 2020. Capacity-building for innovation has become the core of the country's national strategies, marking an important shift in policy. This shift in focus is reflected in the eight primary thrusts of the innovation policies described overleaf.

Box 2: The world's first photonic telephone network

Quantum communication possesses the feature of absolute security which traditional means of communication lack. However, due to the imperfect nature of real systems and the lack of true quantum single-photon sources, the secure communication rate of quantum communication systems declines sharply with increasing distance. This meant that, for a long time, quantum communication was stuck at the laboratory stage.

In April 2009, Professor Pan Jianwei and his research group from the University of Science and Technology of China built the world's first photonic telephone network in Hefei. This shows that absolutely secure quantum communication can be applicable to daily life. The group successfully developed a quantum phone prototype and constructed a photonic telephone network which can be freely expanded based on the commercial fibre network.

This research has taken the lead worldwide in the field of practical quantum communication. As *Science* put it, 'With such a presentation, "quantum privacy" will not be a very distant future in your own home'.

As long ago as 2008, the group established quantum entanglement between two ensembles of cold atoms connected by 300 m fibres, perfectly realizing 'quantum repeaters', which is vital to long-distance quantum communication. This significant outcome was published in the issue of *Nature* dated 28 August 2009. It was listed as one of China's top ten achievements in S&T for 2008.

Source: MOST; University of Science and Technology of China

Box 3: China's supercomputers

China's fastest supercomputer, Tianhe-1 (TH-1), was released in Changsha on 29 October 2009. With a theoretical peak performance of 1.206 PetaFlop per second, TH-1 makes China only the second country after the USA to develop a supercomputer on such a scale. In 2009, TH-1 ranked fifth worldwide on the Top500 organization's list of supercomputers. By 2010, it had climbed to second place, according to a Nebulae report, with a Linpack performance of 1.271 PFlop per second. TH-1 was voted one of China's top ten achievements in S&T for 2009 by 563 academicians of the Chinese Academy of Sciences and Chinese Academy of Engineering.

Funded by the National Programme for High-tech R&D (the 863 programme), the TH-1 project was launched in 2008. TH-1 represents a hybrid design with Intel Xeon processors and GPUs from Advanced Micro Devices Inc. It has wide applications in the fields of resource exploration, biological medicine development, aircraft and space craft development, financial engineering and new materials development.

Source: Xinhua News Agency; www.top500.org/lists/2010/06/press-release

Box 4: The Shanghai Synchrotron Radiation Facility

The Shanghai Synchrotron Radiation Facility (SSRF) was competed in April 2009 after 52 months of construction. It is the biggest scientific platform in China so far and represents an investment of about 1.43 billion Yuan by the central government.

With electron beam energy of 3.5GeV, it is one of the best third-generation light sources in the world. SSRF consists of a 150MeV linear particle accelerator, a booster that can increase the electron energy from 150MeV to 3.5GeV in 0.5 seconds, as well as a 3.5GeV electron storage ring.

SSRF has the capacity to serve hundreds of scientists and engineers in various disciplines from universities, institutes and industry every day.

Source: http://ssrf.sinap.ac.cn/

First thrust: a boost for investment in R&D

- The government has established a diversified investment system for S&T development to ensure that government investment in S&T maintains a faster growth rate than that of regular government revenue, in order to guarantee the implementation of national megaprojects in science and engineering and national S&T programmes.

- The government has optimized the structure of government expenditure on R&D by focusing on basic research, public goods research and frontier technology research and by providing the requisite preferential policies to solve major challenges for national, regional and industrial development. Expenditure on basic research nearly doubled between 2004 and 2008, from 11.72 to 22.08 billion Yuan. Despite this effort, the share of GERD devoted to basic research actually dropped from 5.96% to 4.78% over the same period (*see page* 389).

- The government has devised a new mechanism for managing government expenditure on R&D, in order to improve efficiency and effectiveness, with a focus on expenditure on scientific research, the development of talent and national S&T programmes. It has also established a performance evaluation system to assess government expenditure on R&D.

Second thrust: tax incentives for investment in STI

- The government has formulated additional preferential policies to enable enterprises to upgrade their experimental facilities and instruments, by speeding up the depreciation of imported facilities and instruments for R&D. For example, the government shares 12.5% of enterprise expenditure on R&D by means of tax deductions.

- Government policy provides tax incentives for the technology development centre of enterprises[3] , national engineering research centres[4] , national megaprojects for S&T and national R&D projects involving sophisticated technological equipment, to build innovation capacity in enterprises. Enterprises are entitled to deduct the tariff and related value-added tax from imported goods that are to be used in R&D and when undertaking projects within national S&T programmes.

- The policies devised by the Ministry of Finance and the State Administration of Taxation in 2006–2007 promise to waive the income tax of transformed research institutes[5] to strengthen their capacity for innovation (Box 5). In order to promote the development of small and medium-sized enterprises, tax incentives extend to venture capital and service organizations active in S&T, such as science parks on university campuses and incubators of technology-based enterprises. The policy also encourages social organizations to support innovation via tax-deductible donations.

Third thrust: a government procurement policy to promote innovation

- The government has established a system for purchasing the product of endogenous innovation using government funds. This scheme includes setting

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[3] Creation of a technology development centre within an enterprise is authorized by the National Development and Reform Committee and three other government agencies.

[4] The term national enterprise research centre also refers to a national engineering technology research centre.

[5] Transformed research institutes have been transformed from state-owned research institutes into enterprises (see Box 5).

up a system for authorizing endogenous innovation and giving high priority to the product of endogenous innovation in major national construction projects and other relevant projects.

- The government has taken administrative steps to purchase initially and order products arising from endogenous innovation, in order to encourage enterprises to invest more in innovative product development and capacity-building.

- The government is establishing a scheme that will give high priority to foreign companies prepared to transfer technology to China[6] ; this scheme will comprise a system for authorizing domestic goods and an auditing system for the purchase of foreign goods.

Fourth thrust: innovation based on assimilating imported advanced technology

- Henceforth, key national projects are required to draw up a plan for building innovation capacity based on the assimilation of imported advanced technology.

- The government has modified the list of technologies for which importation is either encouraged or restricted. Enterprises and other bodies are encouraged to import advanced technology for the purposes of design and manufacture.

- The government is giving high priority to key national projects leading to the manufacture of a first batch of equipment in China based on the assimilation of imported advanced technology.

- The government is supporting co-operation among industries, universities and research institutes in assimilating imported advance technologies and innovation. It is also giving high priority to the technology platform in the national programme for S&T infrastructure.

Fifth thrust: capacity-building in generating and protecting IPRs

- In 2007, the Ministry of Science and Technology compiled a list of key technologies and products for which China should hold related patents and which the country should develop within national S&T programmes (MOST, 2007*a*). The ministry also established a platform for an IPR information service to support enterprises in applying for patents.

- The government supports technology standard-setting and is encouraging enterprises to set endogenous technology standards jointly with universities and research institutes, and to integrate these standards in R&D, design and manufacture.

- The government has created an environment conducive to IPR protection by making laws and regulations more effective and by rewarding inventors and major contributors to the commercialization of IPRs held by public organizations.

- The government has shortened the examination cycle for invention patents.

Sixth thrust: building national infrastructure and platforms for STI

- The government has constructed infrastructure and platforms for R&D, including scientific facilities, large equipment and scientific databases. These have been established for use by national laboratories, national engineering laboratories and national engineering research centres.

- By fostering co-operation between enterprises, universities and research institutes, the government is supporting enterprises in their efforts to establish a technology development centre and national engineering laboratories in their midst in key R&D fields. The greatest beneficiaries of this scheme so far have been the transformed research institutes and large enterprises. National engineering laboratories tend to focus on developing pre-competitive technology and frontier technology.

- The government has established a mechanism for sharing platforms for S&T and innovation among users and for evaluating the openness and effectiveness of these platforms.

Seventh thrust: cultivate and utilize talents for STI

- In order to cultivate home-grown talents that are world-class and give them an international perspective, China has recruited more than 800 top foreign scientists and other experts working in China

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[6] One example is the opening of the Airbus (Beijing) Engineering Centre in early 2006, within a joint venture between Airbus and China's two largest aviation companies, the China Aviation Industry Corporation I and II.

Box 5: Milestones on the road to a national innovation system

In 1978, China initiated the first of a series of far-reaching reforms and began opening up to the outside world. The first reform as far as the science system was concerned consisted in extending the decision-making power of R&D institutes and reforming the R&D funding system. This was followed by the gradual introduction of a market mechanism into the S&T system and by S&T-related legislation. The last stage has seen the establishment of a national innovation system favouring S&T-based socio-economic development. The reform of the science system can be divided into four historic stages.

Reconstructing the scientific management system (1978–1985)

The National Science Conference in March 1978 marked a turning point in China. The conference emphasized that 'S&T is the productive force' and that 'the modernization of S&T is the key of the four modernizations', the other three being industry, agriculture and defence. The 1978 conference laid vital ideological and theoretical foundations for the rediscovery of the position, function and influence of S&T in promoting economic development. The conference approved the *Outline of the National Science and Technology Development Plan* (1978–1985) and issued three complementary documents: *Main Tasks of Scientific and Technological Research*, a *National Plan for Basic Science* and a *National Plan for Technological Sciences*. Two critical measures were adopted in this period: the national examination system for higher education was restored in 1978 to develop qualified S&T personnel and the National Leading Group for Science and Technology of the State Council was established in December 1981 to strengthen scientific management.

Reforming the science system (1985–1992)

In March 1985, the Central Committee of the Communist Party of China (CCCPC) proposed a strategic guideline that 'economic development must rely on S&T, while the development of S&T must be oriented towards serving economic development' (CCCPC, 1985). This guideline served as a roadmap for the reform of the science system. It had five main thrusts, namely to:

- reform the funding system for S&T and manage funding;
- implement a technology contract system, so as to develop the market for technology and promote the commercialization of research results;
- introduce a market mechanism and adjust the organizational structure of S&T, in order to strengthen enterprises' capacity for technology development;
- empower research institutes by giving them the right to self-determination and independent status;
- reform the system of S&T personnel management and implement a merit-based pay system.

Between 1982 and 1990, China promulgated several laws and regulations that included the Trademark Law (1982), Patent Law (1984), Technology Contract Law (1987) and Copyright Law (1990).

It also improved the national S&T awards system by adjusting existing awards and setting up new ones, including the: National Natural Science Award, National Invention Award and National Science and Technology Progress Award. In parallel, China adopted a series of important policy measures to adapt institutions and policies to the needs of socio-economic development, including: establishing the National Natural Science Foundation of China; initiating the National High-Tech R&D Programme, also known as the 863 programme because it was proposed by four top Chinese scientists in March 1986; creating high-tech industrial development zones and; encouraging the development of technology-based enterprises.

Making S&T an integral part of the economy (1992–1998)

In 1992, China proposed establishing a socialist market economy. In order to make S&T an integral part of the economy, the government proposed adjusting the allocation pattern for resources destined for S&T. A key policy measure was the instigation of the Combination Development Project for Industries, Universities and Research Institutes in April 1992 by the State Economic and Trade Commission, in tandem with the State Education Commission and Chinese Academy of Sciences.

The Science and Technology Progress Law, promulgated in July l993, resolved some fundamental legal issues. For instance, it defined the objective and key tasks of S&T activities and related policies. To make sure R&D was not ignored in the process of integrating S&T in the economy, the CCCPC and State Council issued the Decision on Accelerating the Progress of Science and Technology (1995), which emphasized, as in 1985, that 'economic construction must rely on S&T, while the development of S&T must be oriented towards serving economic development' but, significantly, added to this the mention 'towards scaling the heights of world S&T'.

In order to promote the economic integration of S&T, China formulated the Law on Promoting the Transformation of Scientific and Technological Achievements in May 1996. This law provides legal protection for the commercialization of research results. Thereafter, the government advocated orienting scientific research institutes towards economic development by having them: join an enterprise as a technology development arm for the enterprise or an industrial sector; function according to the operational mechanism of corporations; set up enterprises or become an enterprise themselves; become a technological service organization (State Council, 1996).

In order to 'scale the heights of world S&T', the government initiated the National Key Basic R&D Programme. This is also known as the 973 programme because it was approved by the State Leading Group for Science and Education[11] of the State Council in March 1997.

Building a national innovation system (1998–2005)

In June 1998, the State Leading Group for Science and Education decided to initiate the Knowledge Innovation Programme (KIP) by supporting the pilot project of the Chinese Academy of Sciences, in order to create a national innovation system and knowledge economy. The goal of KIP was to build the Chinese Academy of Sciences into a leading academic institution and comprehensive R&D centre in the natural and engineering sciences and in high-tech innovation, turn it into a scientific research base of international standing, an incubator of talented S&T personnel and a springboard for the development of China's high-tech industries.

In order to strengthen linkages between the different actors of S&T and develop an enterprise-centred technological innovation system, the government decided to transform 242 state-owned research institutes into state-owned enterprises in February 2009. This process can only two take forms: either the institute joins an existing enterprise or it becomes a state-owned enterprise itself.

These 242 research institutes were affiliated to 10 former ministries that included the Ministry of Machine Building, the Ministry of the Metallurgy Industry and the Ministry of Coal. By the end of 1999, all had been transformed into state-owned enterprises: 131 had joined large enterprises, 40 had become enterprises, 18 had become technological service organizations and 29 had been transformed into 12 large self-supporting, technology-based enterprises owned by the central government. In order to support the industrialization of these 242 institutions, the central government adopted preferential policies concerning taxation, loans, subsidies and personnel.

In June 1999, the government established the Innovation Fund for Technology-based Small Enterprises. It also implemented a Strategy for Rejuvenating Trade by Means of Science and Technology, with a view to promoting quality high-tech exports. The Decision issued by CCCPC and State Council in August 1999 on *Strengthening Technological Innovation to Develop and Industrialize High-tech* gave an additional boost to the commercialization of research results. In June 2000, the government adopted preferential policies concerning investment, financing, taxation, talented personnel and the intellectual property protection to promote the development of software and integrated circuit industry (State Council, 2000).

In June 2002, China promulgated the *Outline of the National Talents Construction Plan (2002–2005)* and proposed a Strategy for Reinvigorating China with its Talented Human Resources. In December 2003, the CCCPC and the State Council issued a *Decision on Further Strengthening the Work of Talented Personnel.* It emphasized that 'China must incorporate the work of talented personnel in the overall planning of national socio-economic development, vigorously develop human resources and reinvigorate the nation by using its talent'.

Source: author

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[11] 11. Consisting of the National Development and Reform Commission, Ministry of Education, Ministry of Science and Technology, Ministry of Finance, Ministry of Agriculture, Ministry of Traffic and Transportation, Chinese Academy of Sciences, Chinese Academy of Social Sciences, Chinese Academy of Engineering, National Natural Science Foundation and Chinese Association for Science and Technology.

via its Recruitment Programme of Global Experts, known as the Thousand Talents Programme. This programme plans to recruit 2 000 overseas experts over the next five to ten years for national laboratories, leading enterprises and selected research institutes, as well as a number of universities.

- In order to woo talented Chinese scientists and engineers living abroad in particular, the government is backstopping efforts by enterprises to reform income distribution and incentive measures for staff by implementing preferential policies that include special government subsidies, tax breaks and benefit-sharing arrangements for original patents.

Eighth thrust: support endogenous innovation via financial measures

- The government has instructed policy-oriented funding bodies to give priority to financing national megaprojects for S&T, national projects for the industrialization of high technology, the assimilation of imported advanced technology and the export of high-tech products.

- To ease the financial burden on small and medium-sized enterprises, the government has improved the financial services available to them for innovation, established a credit system for them and facilitated venture capital. In parallel, it has improved the legal framework for innovation by making it easier for venture capital to invest in start-ups.

- The government has established multiple capital markets to support endogenous innovation, including a stock market for technology-based small and medium-sized enterprises, stock transactions for high-tech enterprises and a regional transaction market for property rights.

THE NATIONAL S&T PROGRAMMES

China's national S&T programmes encompass three major programmes:

- the **National Programme for High-tech R&D** (the 863 programme), which received an allocation from the central government of 5.6 billion Yuan (US$ 805.2 million) in 2008;

- the **National Programme for Key Technology R&D**, which received an allocation of 5.1 billion Yuan (US$ 729.5 million) in 2008;

- the **National Programme for Key Basic R&D** (the 973 programme), which received 1.9 billion Yuan (US$ 273.6 million) in 2008.

In 2008, these three programmes represented two-thirds (12.6 billion Yuan) of the central government's allocation to national S&T programmes (17.6 billion Yuan). A further 1.8 billion Yuan went to the national programme for the construction of basic infrastructure like national key laboratories, which consumed most of its budget (1.6 billion Yuan).

A further 3.2 billion Yuan went to national policy-oriented programmes and special programmes. Their budget encompasses the:

- Innovation Fund for Small Technology-based Firms (1.462 billion Yuan);
- International S&T Co-operation Programme (400 million Yuan);
- Agricultural S&T Transfer Fund (300 million Yuan);
- Special Technology Development Project for Research Institutes (250 million Yuan);
- Spark Programme[7] (200 million Yuan);
- Torch Programme[8] (152 million Yuan);
- National New Products Programme (150 million Yuan);
- Soft Science Programme[9] (25 million Yuan);
- other special programmes (300 million Yuan).

Last but not least, the National Natural Science Foundation of China increased its project funding for basic research from 4.1 billion Yuan in 2006 to 6.3 billion Yuan in 2008. However, the growth rate of expenditure on basic research remains lower than that of R&D expenditure because of the rapid expansion of experimental development in enterprises (*see page* 389).

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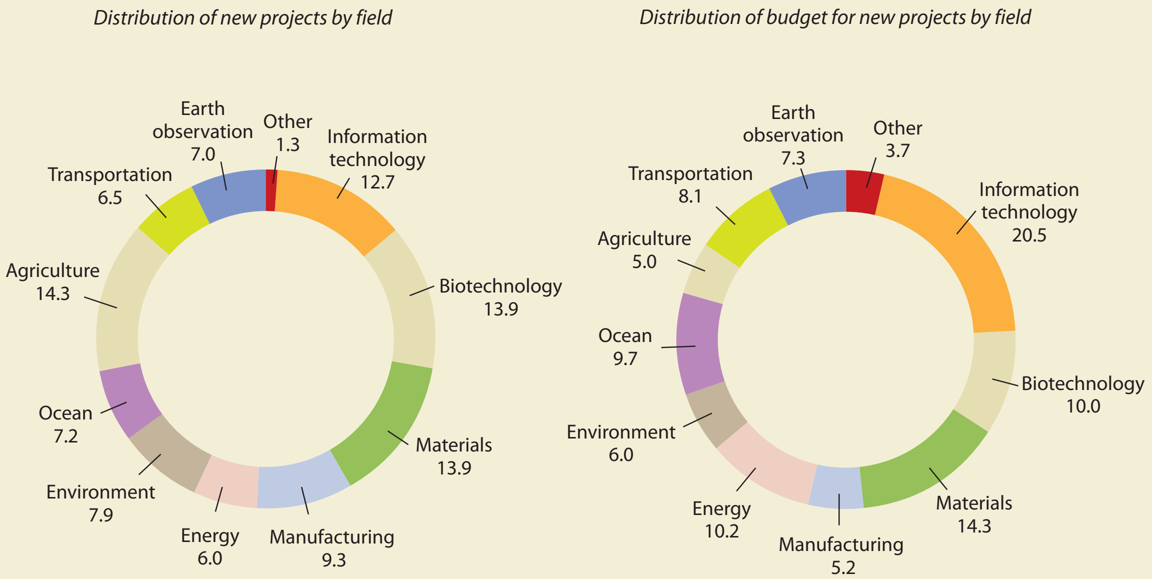
7. The Spark Programme was launched in 1986 to promote S&T development in rural areas, raise rural productivity and promote an S&T-based rural economy.

8. Launched in August 1988, the Torch Programme focuses on the development of high-tech industries. Implemented via project demonstration, the Torch Programme aims to commercialize those high-tech products with good market prospects and to develop new products in high-tech and related industries. This includes establishing some high-tech industrial development zones around China.

9. Soft science is interdisciplinary research involving natural and social sciences, engineering and mathematics in support of the decision-making process.

Figure 1: Priorities of China's National Programme for High-tech R&D, 2008 (%)



Source: MOST (2009*b*) *Annual Report of the State Programs of Science and Technology Development*

The R&D priorities of the three main programmes

China's national S&T programmes have set their priorities for R&D according to the five strategic areas identified in the *Outline of the Medium- and Long- Term Plan for National Science and Technology Development* (2006–2020). During 2006–2008, the central government's appropriation for these five strategic areas accounted for 90% of the budget allocated to the three major national S&T programmes (MOST, 2009*b*):

- Energy resources and environmental protection: 10.1 billion Yuan (19.8% of the total appropriation);
- IT, new materials and manufacturing: 12.2 billion Yuan (23.8% of the total appropriation);
- Agriculture, population and health: 11.9 billion Yuan (23.8% of the total appropriation);
- Space and ocean technology: 2.5 billion Yuan (4.9% of the total appropriation);
- Basic sciences and frontier technology: 9.7 billion Yuan (19% of the total appropriation).

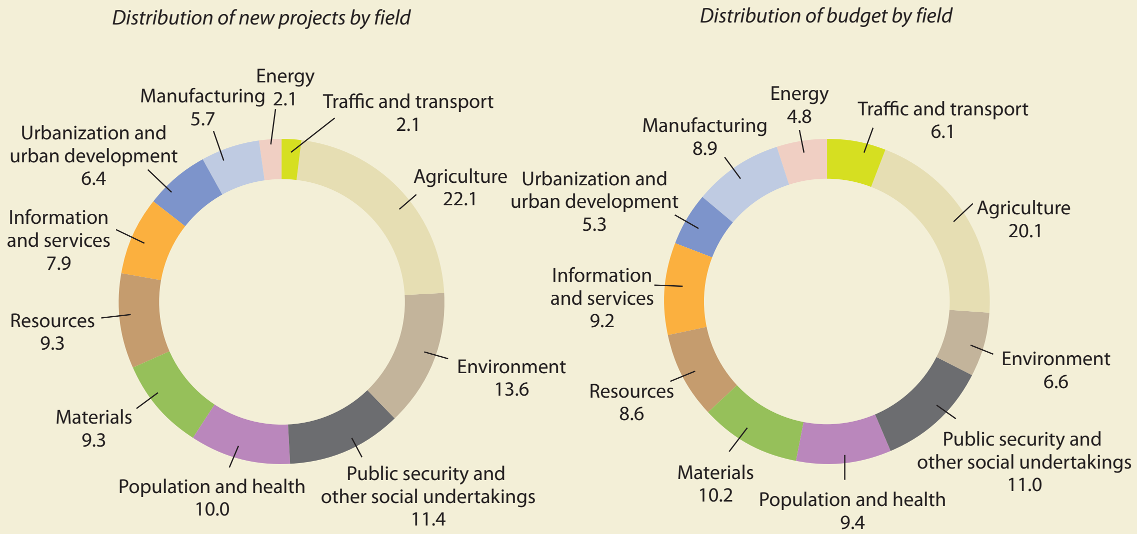
National Programme for High-tech R&D

The 863 programme covers 10 fields of technology. In 2008, the programme approved 1 220 new projects spread fairly evenly across all 10 fields, half of the projects being related to agriculture, materials science, biotechnology and IT. Funding, on the other hand, tended to favour IT (see, for example, Box 3), followed by materials science, energy, biotechnology and ocean science (Figure 1). Universities undertake 57.9% of ongoing projects within the 863 programme, compared to 28.5% for research institutes and just 13.5% for enterprises. Interestingly, enterprises fund much more R&D than they perform within the 863 programme: (24.4%), compared to 43.7% for universities and 31.7% for research institutes.

National Programme for Key Technology R&D

The National Programme for Key Technology R&D covers 11 fields. In 2008, it approved 140 new projects (Figure 2). The central government appropriation was largest by far for agriculture (20.1%). Within this programme,

Figure 2: Priorities of China's National Programme for Key Technology R&D, 2008 (%)

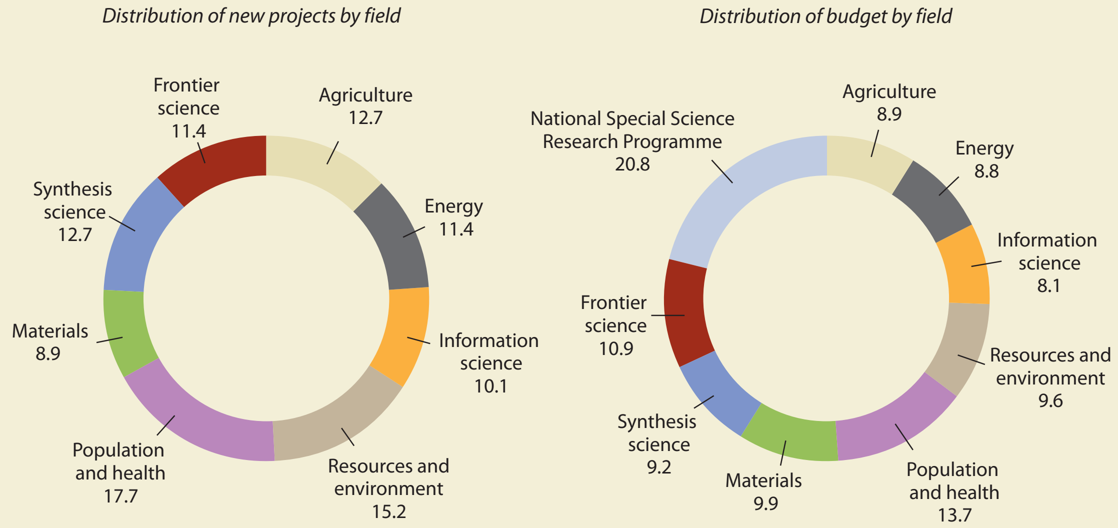


Distribution of new projects by field

Distribution of budget by field

Source: MOST (2009b); *Annual Report of the State Programs of Science and Technology Development*; *NBS and MOST (2010) China Statistical Yearbook on Science and Technology 2009*

Figure 3: Priorities of China's National Programme for Key Basic R&D, 2008 (%)



Distribution of new projects by field

Distribution of budget by field

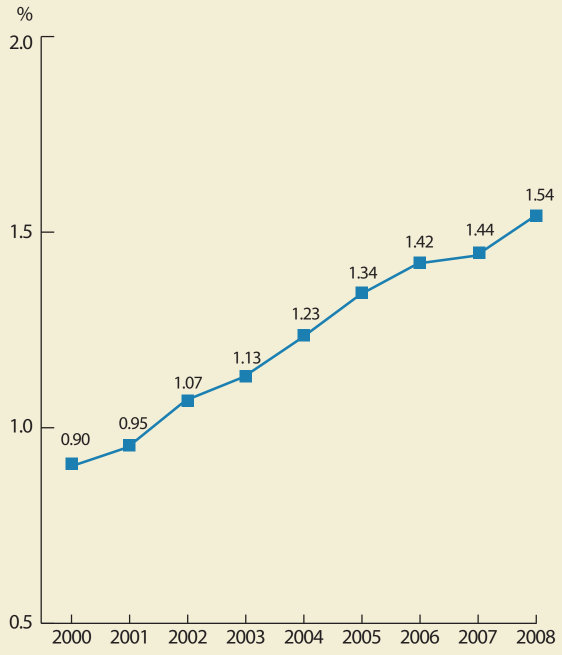
Note: The new projects here do not include those within the National Special Science Research Programme, the breakdown of which is as follows: nano-research (34.3%), development and reproduction research (25.7%), protein research (22.9%) and quantum manipulation (17.1%).

Source: MOST (2009b) *Annual Report of the State Programs of Science and Technology Development* universities undertake 26.4% of projects, compared to 18.1% for research institutes and 44.4% for enterprises. Other players account for 11.1% of these projects.

National Programme for Key Basic R&D

The 973 programme covers eight fields. Since, 2006, it has also been supporting the National Special Science Research Programme, which consists of four evenly balanced key research projects: nano-research, development and reproduction research, protein research and quantum manipulation. In 2008, the National Special Science Research Programme accounted for 20.8% of the government appropriation (Figure 3). The same year, the 973 programme approved 79 new projects in the eight traditional fields and 35 new projects within the National Special Science Research programme. In addition to these new projects, there were 274 ongoing projects within the 973 programme in the eight traditional fields and 82 within the National Special Science Research Programme. Universities undertake more than half (54.5%) of all ongoing projects within the 973 programme, research institutes and enterprises performing 41.9% and 3.1% of R&D respectively.

Figure 4: GERD/GDP ratio in China, 2000–2008 (%)



Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the New Geography of Science.* Thomson Reuters

R&D INPUT

A steep rise in R&D expenditure

In less than a decade, China has become one of the world's biggest spenders on R&D[10]. Between 2000 and 2008, GERD leapt from 89.6 billion Yuan (US$ 10.8 billion) to 461.6 billion Yuan (US$ 66.5 billion), at an average annual growth rate of 22.8%. The ratio of GERD to GDP in China has likewise increased: from 0.90% in 2000 to 1.54% 2008 (Figure 4). Despite this performance, China's R&D intensity still lags behind that of most developed countries. At US$ 368.1 billion, GERD in the USA was about 5.5 times that of China in 2007, for example, and 58.5 times that of India (World Bank, 2009). In 2008, the GERD/GDP ratio was 2.67% in the USA, 3.40% in Japan and 1.80% in the UK (*see page* 62). The *Medium- and Long- Term Plan* does, however, fix the target of raising China's GERD/GDP ratio to 2.50% by 2020.

In China, the lion's share of GERD goes to experimental development (83%), compared to just 5% for basic research (Figure 5). Despite basic sciences and frontier research being one of the five strategic areas for R&D to 2020, the share of GERD devoted to basic research actually dropped in China between 2004 and 2008 from 5.96% to 4.78%, even if expenditure on basic research nearly doubled from 11.72 to 22.08 billion Yuan over the same period. Although the R&D expenditure of enterprises leapt from 131.40 billion to 338.17 billion Yuan over the same period, the majority of this expenditure goes to experimental development. Among industrial enterprises with total revenue from product sales of over 5 million Yuan for example, R&D expenditure amounted to 307.31 billion Yuan in 2008, 98.55% of which was destined for experimental development (NBS and MOST, 2010).

Business enterprises have become big R&D spenders, contributing 59.95% of GERD in 2000 and 73.26% in 2008 (Table 1). There are two reasons for this rapid growth. *Firstly,* more and more enterprises have come to regard innovation capacity as a core competence. Some Chinese firms are expanding their R&D activities globally. For example, Huawei has set up five research institutes in Silicon Valley and Dallas (USA), Bangalore (India), Sweden and Russia to access

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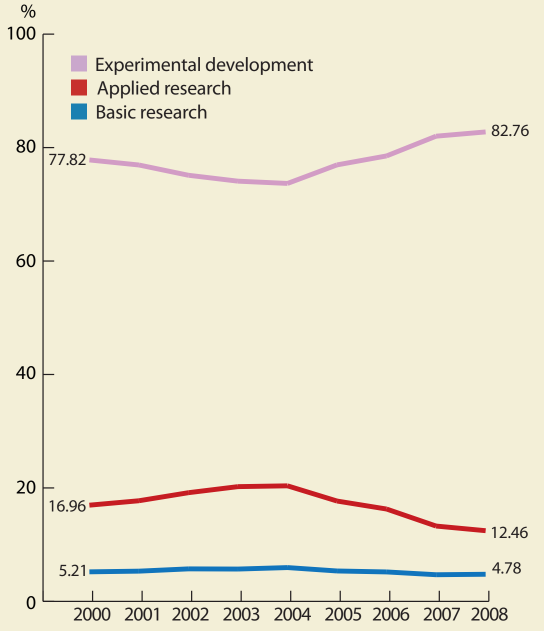
[10] R&D expenditure in the present chapter refers to intramural R&D expenditure.

world knowledge (OECD, 2008). Other enterprises like Lenovo and GEELY are accessing foreign R&D resources by means of transnational acquisitions. This phenomenon is also being observed in India (*see page* 363). Secondly, many public research institutes have been transformed into technology-based enterprises and are thus also playing a role in improving the innovation capacity of industry.

Figure 5: GERD in China by type of research, 2000–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

One of the world's biggest reservoirs of R&D personnel

China has become one of the world's biggest reservoirs of R&D personnel. The number of scientists and engineers more than doubled between 2000 and 2008 to 1.59 million (Table 2). Over the same period, both the share of GDP and the share of GERD spent on each researcher likewise increased. Despite this feat, the density of researchers in China remains lower than that of developed countries, even if China is rapidly closing the gap. In 2007, there were 1 071 researchers per million population in China, compared to 5 573 in Japan, 4 663 in the USA (2006), 3 532 in Germany and 4 181 in the UK (*see page* 8).

Table 1: GERD in China by performing sector, 2000–2008

	Total (Yuan billions)	R&D institutes (Yuan billions)	Enterprises (Yuan billions)	Higher education (Yuan billions)	Other (Yuan billions)	Enterprises (% of total)
2000	89.6	25.8	53.7	7.7	2.4	59.96
2001	104.3	28.8	63.0	10.2	2.2	60.43
2002	128.8	35.1	78.8	13.1	1.8	61.18
2003	154.0	39.9	96.0	16.2	1.8	62.37
2004	196.6	43.2	131.4	20.1	2.0	66.83
2005	245.0	51.3	167.4	24.2	2.1	68.32
2006	300.3	56.7	213.5	27.7	2.4	71.08
2007	371.0	68.8	268.2	31.5	2.6	72.28
2008	461.60	81.13	338.2	39.0	3.3	73.26

Sources: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

Table 2: Researchers in China, 2000–2008

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Researchers (thousands)	695.10	742.70	810.50	862.11	926.20	1 118.70	1 223.76	1 423.40	1 592.40
GDP per researcher (million Yuan)	14.27	14.76	14.85	15.75	17.26	16.38	17.32	17.53	18.88
GERD per researcher (thousand Yuan)	128.85	140.36	158.87	178.59	212.30	219.00	245.40	260.66	289.88

Note: Here, the term 'researcher' refers to scientists and engineers among R&D personnel in Chinese statistical yearbooks, a comparable indicator to 'researchers' in OECD statistics.

Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; NBS (2010) *China Statistical Yearbook 2009*

Table 3: Citation rate for Chinese scientific papers, 1998–2008

	USA	Japan	Germany	UK	China	France	Italy	India	Korea
ESI papers	2 959 661	796 807	766 146	678 686	573 486	548 279	394 428	237 364	218 077
Citations	42 269 694	7 201 664	8 787 460	8 768 475	2 646 085	5 933 187	4 044 512	1 088 425	1 256 724
Citation rate	14.28	9.04	11.47	12.92	4.61	10.82	10.25	4.59	5.76

Note: These data cover Essential Science Indicators for the period from 1 January 1998 to 31 August 2008.

Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; OECD (2009) *Main Science and Technology Indicators*, Volume 2009/1

Table 4: China's global share of publications by major field of science, 1999–2008

	1999–2003		2004–2008	
	Count	World share %	Count	World share %
Materials science	20 847	12.22	48 210	20.83
Chemistry	44 573	9.29	99 206	16.90
Physics	31 103	7.97	66 153	14.16
Mathematics	7 321	7.37	16 029	12.82
Engineering	19 343	6.42	43 162	10.92
Computer science	3 943	4.54	16 009	10.66
Geosciences	5 322	4.95	12 673	9.30
Pharmacology & toxicology	2 259	3.11	6 614	7.28
Environment/ecology	3 171	3.26	9 032	6.85
Space science	2 055	3.80	3 514	5.8b
Biology & biochemistry	6 697	2.66	15 971	5.86
Plant & animal science	5 915	2.61	14 646	5.42
Agricultural sciences	1 082	1.48	4 872	4.88
Microbiology	921	1.38	3 863	4.74
Molecular biology & genetics	1 642	1.43	6 210	4.49
Immunology	493	0.87	2 114	3.51

Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the new Geography of Science*

R&D OUTPUT

Only the USA and Japan now publish more

China has become one of the world's most prolific countries for scientific authorship. In 2000, it ranked eighth in the world, according to the database of Thomson Reuters' Science Citation Index (SCI). By 2007, it had climbed to third place. Over the same period, the number of SCI papers published by Chinese researchers nearly tripled from 30 499 to 89 147, representing an average growth rate of 17.3% (NBS and MOST, 2010). However, the average citation rate for Chinese papers in the Essential Science Indicators database during the period 1999–2008 was only 4.61 (Table 3). This indicates that there is still a wide gap in the quality of scientific publications between China and the world leaders in S&T. Of note is that China and India share a similar citation rate. (See pages 374 and 375 for a comparison of Brazilian, Indian and Chinese papers recorded in the SCI database between 2000 and 2008.) China is most influential in materials science, where it represented 20.83% of global output between 2004 and 2008 (Table 4).

Rapid growth in patents

China has become one of the most prolific countries in terms of applications for, and grants of, domestic resident invention patents (Figure 6). Moreover, in 2008, a total of 77 501 domestic resident invention patents were granted in the USA, about 1.66 times as many as in China.

The efficiency of Chinese researchers in terms of invention patents is much lower than that of most developed countries. Some 22.4 domestic resident invention patents were granted per thousand researchers in China in 2007, compared to 412.9 in the Republic of Korea, 204.3 in Japan, 45.6 in Germany and 63.0 in the USA (2006). The landscape for filing within the Patent Co-operation Treaty (PCT) offers almost the same view. In 2007, China filed 3.8 PCT patents per thousand researchers, far fewer than Germany (62.7), Japan (39.1) or the USA (36.0) [Table 5].

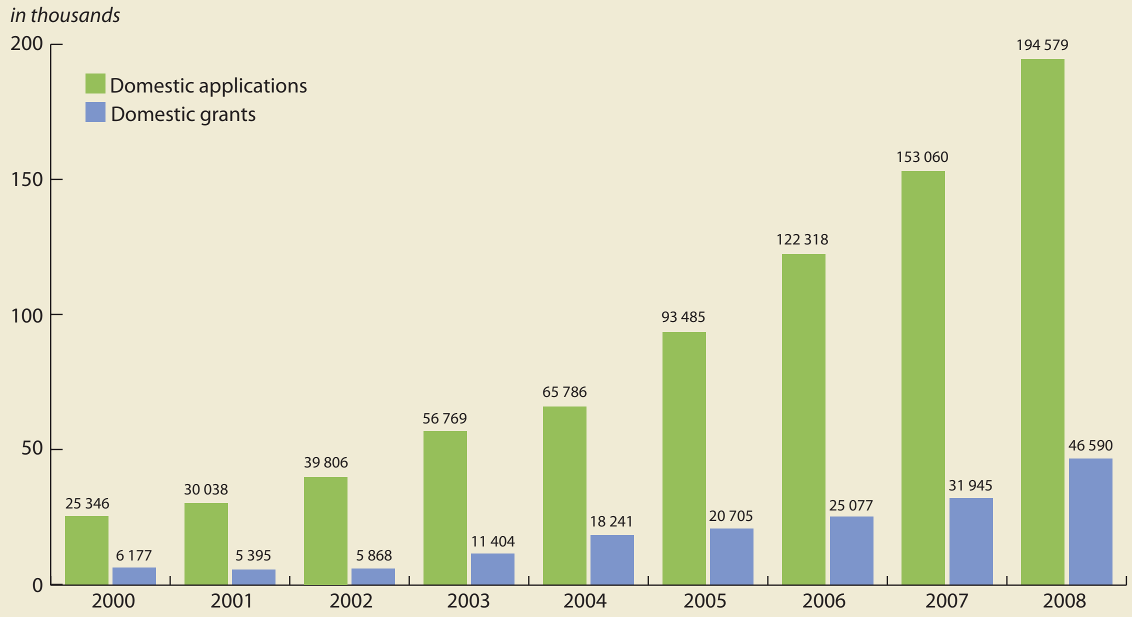
A CLOSER LOOK AT HIGH-TECH INDUSTRIES

Rapid growth in high-tech industries since 2000

High-tech industries in China consist in the manufacture of:

- medicines, medical equipment and measuring instruments;
- aircraft and spacecraft;
- electronic equipment;
- telecommunications equipment;
- computers and office equipment.

Figure 6: Growth in Chinese domestic resident invention patents, 2000–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*

Table 5: Domestic invention patent grants and PCT patent filings in China, 2007

	Japan	Rep. Korea	USA	China	Russia	Germany	France	UK
Domestic invention patents granted	145 040	91 645	89 823	31 945	18 431	12 977	10 697	2 058
PCT patent filings	27 749	7 065	51 296	5 465	735	17 825	6 264	5 539
Researchers (thousands FTE)	710.0	221.9	1425.6	1423.4	469.1	284.3	211.1	175.5
Domestic invention patents granted per thousand researchers	204.3	412.9	63.0	22.4	39.3	45.6	50.7	11.7
PCT filing per thousand researchers	39.1	31.8	36.0	3.8	1.6	62.7	29.7	31.6

Note: Data are 2006 for the USA and France.

Source: WIPO database; OECD database

High-tech industries in China have experienced rapid growth in the past 10 years. The value of gross industrial output of high-tech industries leapt between 2000 and 2008 from 1 041.1 billion Yuan (US$ 125.8 billion) to 5 708.7 billion Yuan (US$ 822.0 billion). Over the same period, the number of employees more than doubled from 3.9 million to 9.5 million.

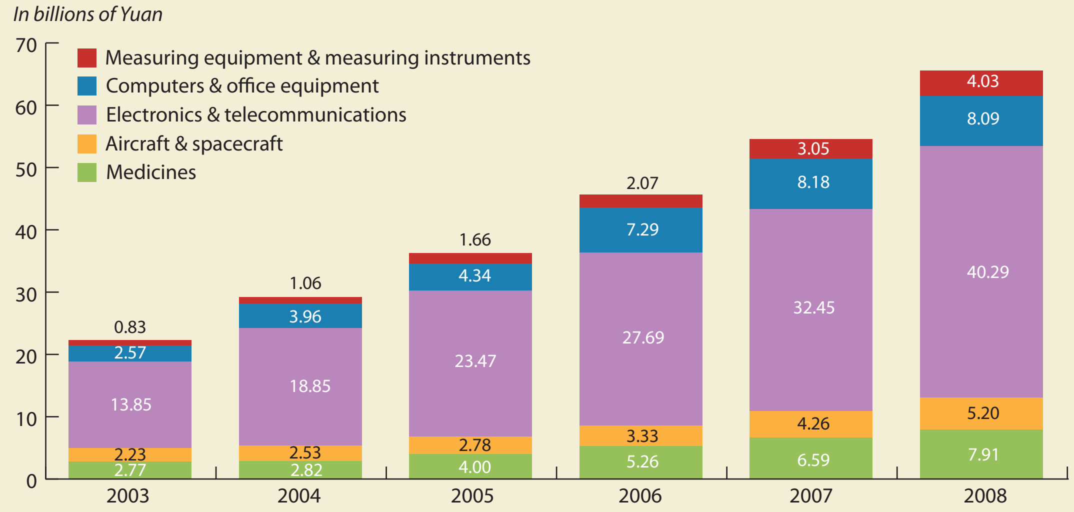
R&D expenditure by high-tech industries tripled in just five years: from 22.2 billion Yuan in 2003 to 65.5 billion Yuan in 2008, growing at an average annual rate of 24.1%. Electronics and telecommunications accounted for 61.5% of all high-tech expenditure on R&D in 2008 (Figure 7). Despite these impressive figures, the R&D intensity of high-tech industry in China remains much lower than that of developed countries. In 2008, the ratio of R&D expenditure to the value of gross industrial output of high-tech industries was just 1.15% in China. This was much lower than the 2006 ratio for the USA (16.41%), the UK (11.04%), Japan (10.64%), Germany (8.34%) or the Republic of Korea (5.98%), according to the 2008 databases of the Organisation for Economic Co-operation and Development (OECD) on Structural Analysis Statistics (STAN) and Analytical Business Enterprise Research and Development (2009).

R&D personnel in high-tech industries in China has experienced remarkable growth, after a fleeting dip from 2003 to 2004. In 2008, there were 285 100 full-time equivalent researchers, more than twice the number in 2003. Not surprisingly, 60.4% of R&D personnel working for high-tech industries were employed in electronics and telecommunications in 2008 (Figure 8).

The number of applications for invention, utility model and design patents in high-tech industries grew annually by 36.8% during 2003–2008. Again, electronics and telecommunications accounted for 65.3% of the total in 2008. However, the fastest annual growth (50.6%) concerned medical equipment and measuring instruments (Figure 9).

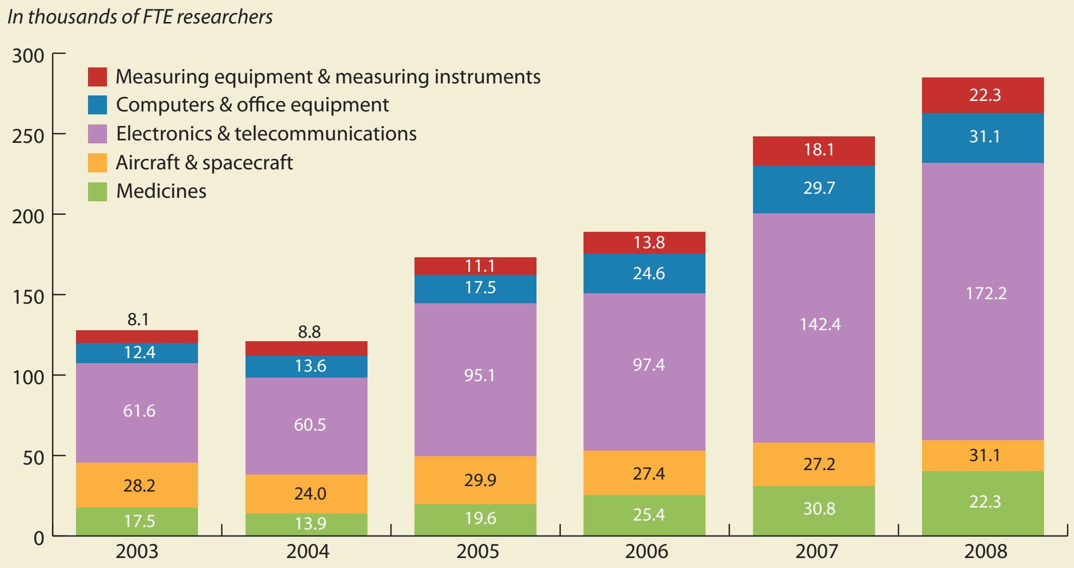
The share of high-tech exports in manufactured exports grew steadily in China between 2000 and 2008, at 8.1% per year. Many dominant players in S&T saw this percentage decline over the same period (Figure 10). Notwithstanding this, China is still a net technology importer. In 2008, China paid US$ 10.3 billion in royalties and license fees, earning receipts of only US$ 570.5 million (State Administration of Foreign Exchange, 2010). The same year, China spent US$ 27.1 billion on imported technology from 82 countries. Of this, US$ 23.5 billion corresponded to technology and US$ 3.6 billion to equipment. Four countries account for two-thirds of China's technology imports: the USA (18.71%), Japan (17.93%), Republic of Korea (12.15%) and Germany (11.75%).

Figure 7: Intramural expenditure on R&D by China's high-tech industries, 2003–2008



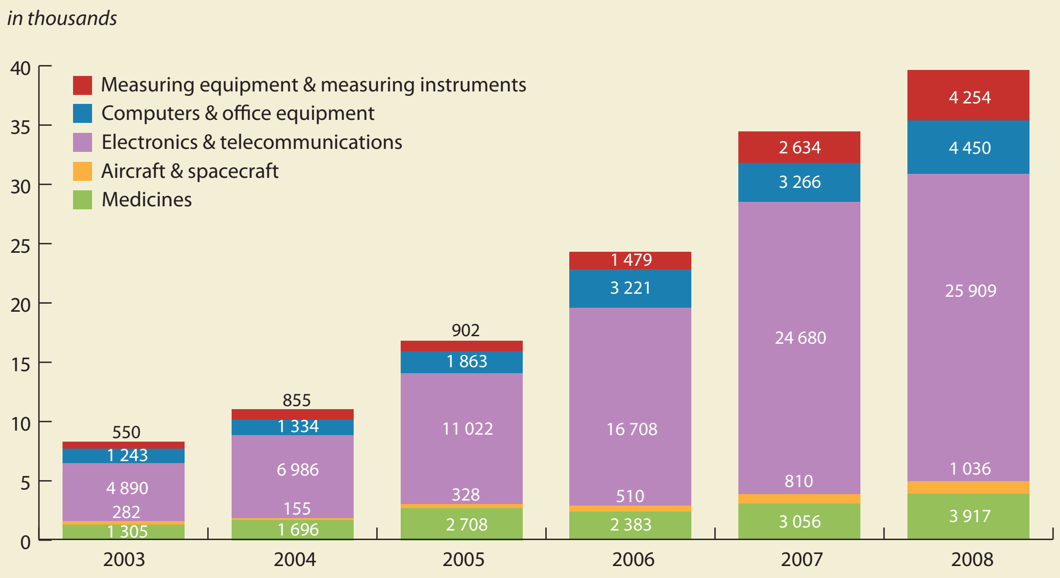
Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

Figure 8: R&D personnel in China's high-tech industries, 2003–2008



Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

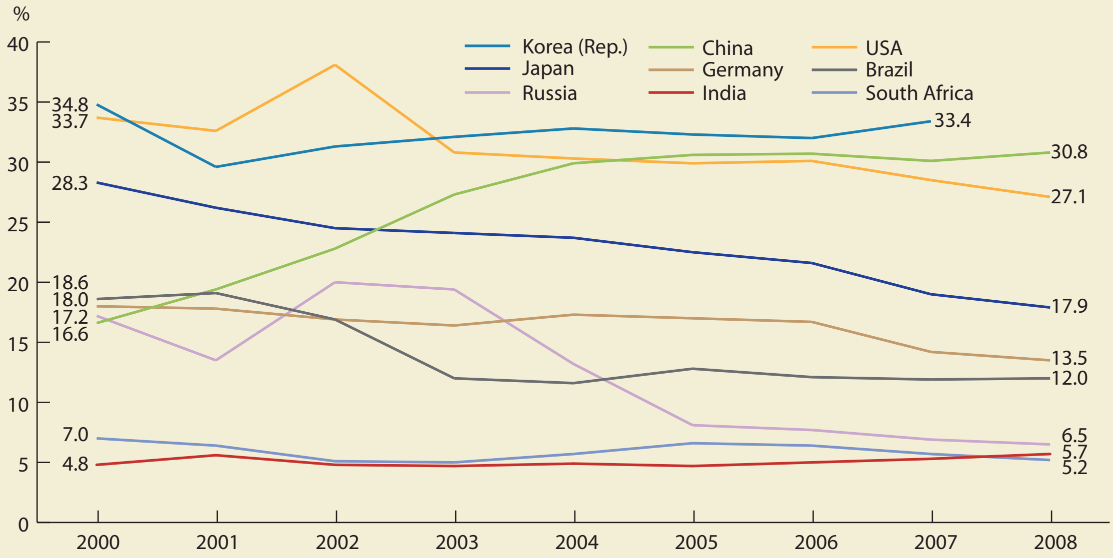
Figure 9: Domestic patent applications by Chinese high-tech industries, 2003–2008



Source: NBS, NDRC and MOST (2008) *China Statistics Yearbook on High Technology Industry*; NBS, NDRC and MOST (2009) *China Statistics Yearbook on High Technology Industry*

Figure 10: Share of high-tech exports in manufactured exports in China, 2000–2008

Other countries are given for comparison



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009*; for other countries: World Bank (2010) *High-technology Exports*

Measuring China's capacity to innovate

The National Innovative Development Index

The National Innovative Development Index (NIDI) covers five areas, namely:

- Industrialization: this represents the transition from a rural economy to an industrial economy characterized by a high S&T content, good economic returns, lower resource consumption, less environmental pollution and a wide spectrum of human resource advantages;
- 'Informationization': this refers to the development of an information society via the utilization of information technology, information exchange and knowledge sharing.
- Urbanization;
- Education and health;
- Science, technology and innovation.

According to the *China Innovation Development Report* (CAS, 2009), China's NIDI experienced fairly rapid growth between 2000 and 2006 of 5.3% per annum. Even so, there remains a yawning gap between China and developed countries for this index. China's NIDI amounted to just 20.94, placing it far behind the leader, Sweden (67.01), and 32nd out of the 34 countries studied in 2006, which included the member states of the European Union, Canada, Japan, the Republic of Korea and USA. China ranked higher than South Africa (33rd) and India (34th) but trailed Brazil (27th), Mexico, Russia, Turkey and Romania. China performed best for education (28th) and worst when it came to industrialization that was respectful of the environment (34th).

The National Innovation Capacity Index

In a broad sense, a country's national innovation capacity is its ability to transform STI into wealth. The National Innovation Capacity Index (NICI) is determined not only by the efficiency and intensity of innovation but also by the scale of it. According to the *China Innovation Development Report* (2009), China's NICI shot up from 6.96 in 2000 to 19.59 in 2007. This performance was more the result of greater intensity in innovative activity than a reflection of its efficiency. Between 2000 and 2006, China experienced the fastest growth in national innovation capacity of all 38 countries under study, with an annual growth rate of over 16% which saw it climb to 17th place by 2006, between Ireland and Austria. However, China's NICI still fell far short of the countries which topped the index, the USA (56.96), Japan (36.75) and Sweden (26.63). For this indicator, Russia ranked 25th, Brazil 32nd, South Africa 33rd and India 37th.

INTERNATIONAL CO-OPERATION IN S&T

In recent years, China has expanded the scale and scope of international co-operation considerably. By the end of 2008, China had established collaborative partnerships in S&T with 152 countries and regions, and signed 104 agreements with the governments of 97 countries and regions (MOST, 2009*a*).

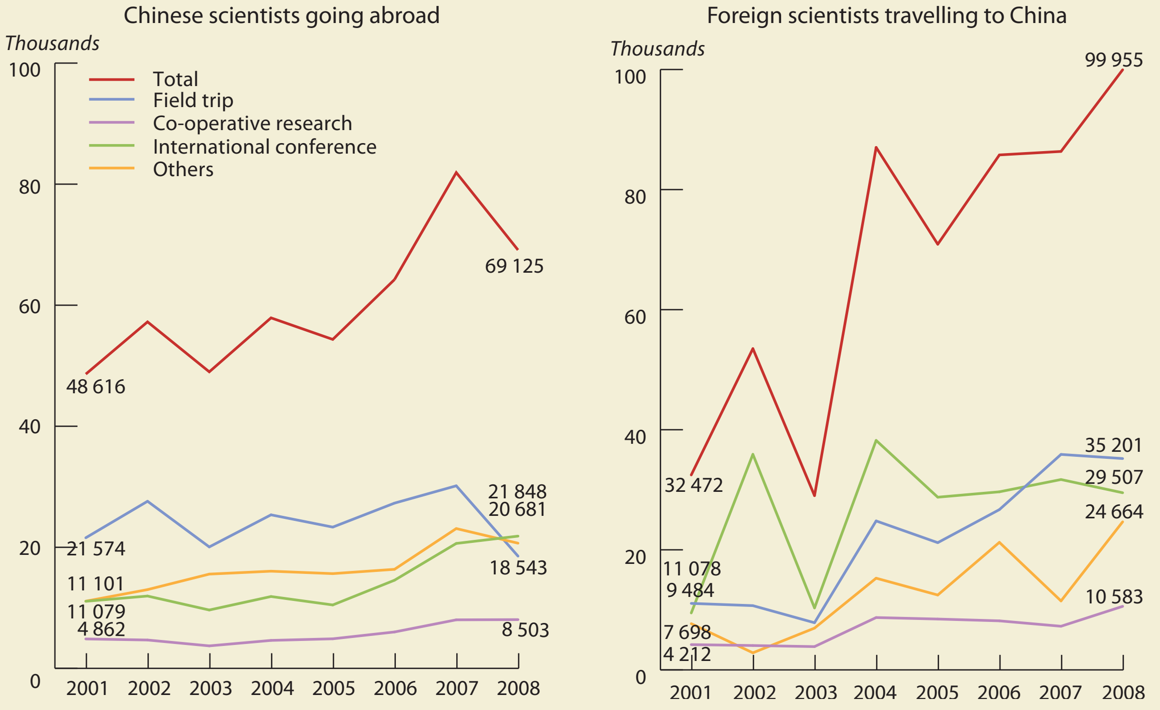
The Chinese government is paying great attention to developing international co-operation in order to improve the country's capacity for innovation. In 2006, it issued the *Outline for the Eleventh Five–Year Plan for Implementing International S&T Cooperation* to diversify the fields covered by co-operation and improve the effectiveness of these partnerships.

In 2001, the government launched the International Science and Technology Co-operation Programme (ISTCP). The ISTCP budget increased steadily over the next seven years from 100 million Yuan to 400 million Yuan in 2008 (NBS and MOST, 2009). In 2001, the National Natural Science Foundation of China created a special fund for international S&T co-operation, the budget of which had nearly doubled by 2008 from 63.9 million Yuan to 144.4 million Yuan.

Over the same seven-year period, the flow of foreign scientists to China exceeded the number of Chinese scientists going abroad, even if the number of mobile Chinese scientists increased gradually from 48 616 in 2001 to 69 125 in 2008. A growing number of Chinese scientists are attending international conferences and participating in international collaborative research. The number of scientists coming to China has almost tripled from 32 472 in 2001 to 99 955 in 2008 (Figure 11).

International co-operation in China has gradually evolved from personal exchanges, communications among academics and the importation of technology to joint research projects, the joint establishment of research institutions and Chinese participation in, or initiation, of megaprojects. China has participated, or is participating, in major international projects that include the European Union's Galileo Global Navigation Satellite System,

Figure 11: Travel by Chinese and foreign scientists by type of project, 2001–2008



Source: NBS and MOST (2010) *China Statistical Yearbook on Science and Technology 2009.*

the Human Genome Project, the Global Earth Observation System, the Integrated Ocean Drilling Programme and the International Thermonuclear Experimental Reactor (Box 6).

Among programmes initiated by China, both the International S&T Co-operation on Traditional Chinese Medicine Programme launched in 2006 and the International S&T Co-operation on New and Renewable Energy Programme launched in 2007 are noteworthy.

International co-operation has produced some remarkable results, as manifested by the rapid growth in joint scientific publications and the rise in both patent applications and technology trade. Chinese scientists co-author articles mostly with their peers from the USA, Japan, the UK, Germany, Canada and Australia. However, co-publications are growing fastest with scientists from Sweden and the Republic of Korea, followed by Canada, Singapore, Australia and the USA (Figure 12).

Box 6: China's role in an international clean energy project

First proposed in 1985, the International Thermonuclear Experimental Reactor (ITER) is the second-biggest international science and engineering project after the International Space Station.

ITER is also the most ambitious international project in which China has taken part so far. China began negotiating its participation in ITER in 2003 before officially signing the ITER Agreement in November 2006. As one of the discretionary and independent members, China will assume 9.09% of the cost of construction and spend over US$ 1 billion in total. Some 1 000 Chinese scientists will participate in the ITER project.

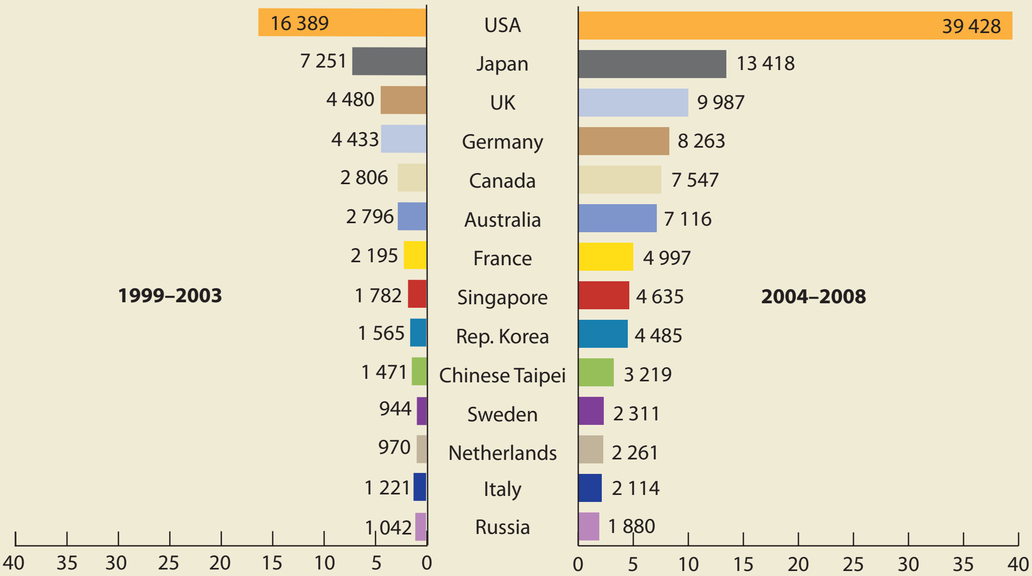
According to the Procurement Arrangement, China will be in charge of developing, installing and testing 12 components, including magnet supports, correction coils and feeders. In February 2007, the State Council authorized the launch of a domestic support programme to fulfil China's obligations vis-à-vis ITER and make full use of the facility once construction has been completed in 2018 or thereabouts.

ITER Director-General Kaname Ikeda has commented that, 'Like other big powers in the world, China, realizing fully the significance of clean energy, is actively taking part in this ITER project, which I think is key to the success of the project'.

Source: www.iterchina.cn/; http://news.xinhuanet.com/

For details of ITER, see page 158.

Figure 12: China's leading research partners, 1999–2008



Source: Adams *et al.* (2009) *Global Research Report China: Research and Collaboration in the New Geography of Science*. Thomson Reuters

CONCLUSION

The series of policies issued by the Chinese government in the past four years for making China an innovation-driven nation by 2020 provide a wide spectrum of measures for inciting enterprises to invest more in innovation and wooing talented scientists living overseas back to serve their homeland.

However, a host of barriers still restrain the development of national innovation capacity in China, especially that of enterprises. This supposes paying greater attention to the three following factors in promoting the development of STI:

- *Firstly,* the innovation risk of enterprises needs to be shared via incentive policies and the development of public infrastructure to support innovation. In parallel, it should be made difficult for enterprises to generate enormous profits without investing massively in innovation.
- *Secondly,* systematic innovation and the exploration of emerging technology must be supported so that breakthroughs become commonplace and Chinese industry is able to leapfrog over leading or emerging industries elsewhere.
- *Thirdly,* the government should continually increase investment in innovation and shape favourable market demands for technology, in order to stimulate the flow of innovative talents from universities and research institutes to enterprises.

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Supportive policies and policy documents for *Outline of Medium- and Long-Term Plan for National Science and Technology Development (2006–2020)*: www.gov.cn/ztzl/kjfzgh/

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