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Is China's Indigenous Innovation Strategy Compatible with Globalization?

Xielin Liu and Peng Cheng

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Contents

List of Acronyms

2G	"Second Generation" (telecommunications standard)
3G	"Third Generation" (telecommunications standard)
4G	"Fourth Generation" (telecommunications standard)
CDMA2000	Code-Division Multiple Access 2000 (telecommunications standard)
EI	Engineering Index
GDP	Gross Domestic Product
ISTP	Index to Scientific and Technical Proceedings
LTE	Long Term Evolution (telecommunications standard)
MII	Ministry of Industry and Information
MOST	Ministry of Science and Technology
NBS	National Bureau of Statistics
NDRC	National Development and Reform Committee
OECD	Organisation for Economic Co-operation and Development
SCI	Science Citation Index
SOE	State-Owned Enterprise

TD-SCDMA	Time Division-Synchronous Code Division Multiple Access (telecommunications standard)
WCDMA	Wideband Code Division Multiple Access (telecommunications standard)
WTO	World Trade Organization

Executive Summary

National innovation policies currently attract intense interest throughout the international community, particularly so in the aftermath of the global financial crisis. China is among those countries now relying heavily on government resources to drive innovation—a policy that directly challenges the prevalent theory that government powers have limited effects on a nation's innovation systems.

Since 2006 China's indigenous innovation strategy has transformed the nation's innovation systems.

First, through establishing government-led research consortia (collaborations involving leading companies and universities and government-led research institutes) and key government-procurement-policy tools, China's government was able to increase its control over the resources available for innovation. While, even after 2006, the government has continued to favor "State-Owned Enterprises" (SOEs) as the main elements for indigenous innovation, during this time private enterprises have become significantly more important relative to these government entities. Regional governments have also simultaneously played important roles in developing China's innovation systems.

Second, in recent years mega-projects developed by government-led research consortia have become increasingly important. Rather than just formulating government policies supporting technological advances, China has used market demand to drive technological innovation. This paper examines the results of the mega-projects developed by government-led and other research consortia.

Chinese research consortia have been structured in many different forms, some controlled by SOEs, some by universities and government-led research institutes, and some by private enterprises. Research consortia have spread from high-tech to traditional industries. Some enjoy local advantages while others do not.

For the case of the recent development of the Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) telecommunications standard, both as a beneficiary of the efforts of a large research consortia and as an example of attempting to define a new industrial standard, it is too early to make a final judgment. Recent developments show that, in terms of industrial success, this effort continues to be a high-risk project.

New innovation systems are emerging in China in response to the nation's indigenous innovation strategy. The old national innovation system used the central government, SOEs, and universities and government-led research institutes as the major elements.

The new systems maintain the central government, SOEs, and universities and government-led research institutes as significant elements but now also are developing innovation from private enterprises, multinational enterprises, and regional governments—with private enterprises significantly becoming the key players.

Private enterprises are now generally the final consumer of most of the research and development done in universities and government-led research institutes and/or supported by government funding. Private enterprises are also now the primary consumers of knowledge spill-over from the various multinational enterprises active in China.

However, Chinese efforts in indigenous innovation still face the challenge of building an innovation network with global impact. China's first challenge is determining whether an exceptionally large domestic market alone is adequate to ensure that indigenous innovation will succeed.

In some industries, such as telecommunications efforts involving TD-SCDMA technology, the market driving the adoption of new technology and hardware is global. Given this reality, whether a new Chinese-developed standard succeeds in the market depends on whether multinational enterprises choose to adopt the technology. The international value of TD-SCDMA is not yet obvious. Companies with large multinational sales, such as Nokia, have been conservative concerning the possible use of this technology. With limited multinational adoptions, TD-SCDMA telecommunications handsets remain very expensive.

However, the current innovation strategy works more effectively in infrastructure-related industries where domestic markets provide the primary demand. In the high-speed-rail sector, for example, the demand is clear. Budgets available for these projects have been massive and government-led consortia have proven successful in addressing the market.

Unfortunately, in most internationally competitive major industries, a strategy that relies primarily on the domestic Chinese market, as exceptionally large as that is, is still limited in its potential. The recent project attempting to market large airplanes provides an example of such a difficulty.

China's second challenge to its developing indigenous innovation strategy involves policy conflicts with western countries. Some western countries argue that current Chinese policy is in conflict with commonly used World Trade Organization (WTO) agreements—especially China's public-procurement policies requiring supplier companies to have a Chinese brand, use Chinese intellectual property, and have at least 51 percent Chinese ownership. However, since China is not yet a signatory to the WTO Agreement on Government Procurement, current Chinese policy on public procurement is legally defensible.

In conclusion, China's current indigenous innovation strategy is both constructive and efficient for an economy with clear targets for industrial innovation working to catch-up to international standards. For China to succeed as an innovative country, it needs to provide more opportunity for market competition to incubate and generate radical innovations.

For the indigenous innovation strategy to succeed, China also needs more open innovation policies than those used in the past. A domestic market that is completely inward-facing will not provide domestic enterprises the space needed to become globally innovative companies. Chinese enterprises cannot succeed if they close themselves off from global technologies. Only open innovation policies will provide Chinese enterprises with the opportunity to succeed in the competition for the next wave of international technological innovation and establish China as a truly innovative nation.

Is China's Indigenous Innovation Strategy Compatible with Globalization?

Introduction

Working to save their national economies following the recent global financial crisis, many countries have expanded their governmental powers addressing the allocation of resources. The proper and effective role of governments in national innovation systems has therefore again become an important issue. In this same period there has been a significant increase in protectionist national policies in many areas, including innovation policies, among both developed and developing countries.

Many countries have expanded their governmental powers addressing the allocation of resources

The recent trend has been to focus on science and technology and innovation policy from the demand side; such a focus has revitalized support for protectionist public procurement policies. The trend can be seen from the European "Barcelona" agreement target for research and development to reach 3 percent of gross domestic product (GDP; European Commission 2003) and in the findings of the "Aho" report (European Commission 2006). Drawing on Ernst (2002), Ahrens (2010) proposed that government procurement contribute to innovation by bridging the finance gap, focusing on market signaling, lowering the risk of research and development, and stimulating demand.

There is no universally shared view on the proper role of government in innovation systems. But the most recent global financial disaster has forced governments worldwide to reconsider their roles in relation to financial crises and innovation systems.

China is a unique country with long legacy of a planned economy. The government here has historically played an important and visible role in directing national innovation systems. A number of government agencies, notably the Ministry of Commerce, the Ministry of Finance, the Ministry of Industry and Information (MII), the Ministry of Science and Technology (MOST), and the National Development and Reform Committee (NDRC), have significantly influenced science and technology and innovation policies and implementation. Other agencies, such as the Ministry of Human Resources and Social Security and the State Intellectual Property Office, also exert important, albeit somewhat indirect, influences. The recent financial crisis provided the Chinese government with even stronger reasons to take a more aggressive role in supporting innovation.

China's national strategy of indigenous innovation was codified in the "2006–2020 Medium- and Long-Term National Science and Technology Development Plan." This plan was officially announced in 2006. Its goal is to make China a globally significant innovative country through the implementation of this indigenous innovation strategy.

Following this strategy China has continued to increase research and development funding even during periods of financial crisis. In 2009 research and development funding in China reached their currently reported highest level at 1.7 percent of GDP.

At the same time, following the global financial crisis, some developed countries allowed their research and development and educational funding to stagnate or even decline. This may explain why China is regarded, in many papers and reports (e.g., Sigurdson and Jiang 2005; Chesbrough 2010), as a rising science and technology and innovation superpower.

China is now a transition economy with the market serving as the basic driving force leading innovation and the government serving in a supporting capacity. There are two reasons for maintaining strong government involvement in innovation: Chinese companies remain weak in developing commercially successful innovations and China's government maintains the power to mobilize national resources for the development of key technologies. Some (e.g., Mei 2009) argue that for China to develop next-generation technology it remains necessary to implement a state-planned innovation system (*juguotizhi*). Such scholars believe the state should be allowed to have even greater power to promote innovation.

Success in facing the reality of globalization and the competitiveness of international markets (especially that of the technology market), however, remains a major challenge for China's national strategy of indigenous innovation. China's markets have now been open to the world since 2001 and China has, consequently, become a primary market for many of the world's latest technologies. The current strategy of indigenous innovation is, to some degree, intended to protect domestic enterprises from global competition while leveraging an exceptionally large domestic market to promote the diffusion of innovative products within China.

Success in facing globalization and international markets remains a major challenge for indigenous innovation

A concern generated by the current policy is whether China's innovation efforts will remain so indigenous that they will not be consistent with developing global technologies. The critical question is whether a primary focus on its exceptionally large domestic market will allow Chinese innovations to achieve the success the government hopes for in the global market.

Since 2001, when China joined the WTO, the Chinese market has been a significant element of the global market. Over this last decade China's strategies of indigenous innovation have actively faced testing in the global market. Since the implementation of the new policy, but especially over 2009–2010, many multinational enterprises operating in China and various Western governments have filed complaints addressing China's public procurement policy and its indigenous innovation strategy.

China's innovation strategy and its threat to American innovation is a "hot-button" topic in China-US economic relations (Ernst 2011). The ongoing debate between China and other developed countries reflects fundamental differences in national industrial policies. Largely the concerns center on the role chosen by China's government regarding its involvement in its national innovation system versus the roles chosen by other developed countries' governments regarding their involvement in their national innovation systems. These international conflicts in policy challenge the implementation of China's indigenous innovation strategy.

Numerous papers and reports have reviewed the Chinese innovation system and innovation strategies (e.g., Liu and White 2001; Lundvall et al. 2006; Ernst and Naughton 2007; Motohashi and Yun 2007; OECD 2008). The Organisation for Economic Co-operation and Development (OECD) review suggested that China needs more "bottom-up" decision making, giving private enterprises a more important role and encouraging more coordination between government agencies to promote innovation (OECD 2008).

Specific actions directly associated with China's innovation strategies use national science and technology programs to drive universities and government-led research institutes, as well as State-Owned Enterprises (SOEs) and private enterprises, to innovate. The most notable of these government actions involve mega-projects.

Indirect actions associated with China's innovation policies include tax subsidies and financial policies created to induce companies to innovate.

At the level of individual private enterprises, however, the inputs and outputs of innovation strategies result in such a multitude of factors it is not realistic to attempt to isolate the true effects of government policy by theoretically controlling other factors. From an academic perspective, now that the government's ambitious innovation strategy has been active for five years, it is sensible to attempt to evaluate its progress. This essay addresses a central question: Can a national strategy for indigenous innovation be made compatible with the globalization of markets, suppliers, and technologies?

The first section of this paper provides a literature review. The second section presents background information on China's indigenous innovation strategy. The third section analyzes how the Chinese government implements its innovation strategy and transforms the innovation system. The fourth section examines how Chinese enterprises respond to the current innovation strategy. The fifth and final section discusses the paper's findings.

Literature Review

Innovation has long been recognized as a significant source of national economic growth (e.g., Schumpeter 1942). It is a powerful element in the economic success of both developed and developing countries. National innovation policy is regarded as one factor in the promotion of economic growth and international competiveness (e.g., Lundvall and Borras 2005). How innovation policy is used to support national innovation is a complex issue in the era of globalization.

Historically there have been three main schools of national innovation policy.

The first, popular in many Western nations, is the "laissez-faire" policy. This policy, while allowing governments to establish certain framework conditions, emphasizes non-intervention by governments other than in the area of basic research. A free market, guided by Adam Smith's often referenced "invisible hand," generates the signals for innovation (e.g., market demand), provides competition, and provides the incentive for individuals and organizations to make the long-term investments in innovation.

In most economies a free market provides the best environment for innovation-resources allocation. Government action only distorts the natural market operation (Bremmer 2010, 26); government intervention is acceptable only in the case of market failures. The case for the support of government involvement in basic research is that the product of such research is information that is costly to produce but almost costless to reproduce and reuse and, therefore, provides significant benefit to the public good. Such beliefs support the conclusion that basic research is an appropriate use of public funding (Arrow 1962).

In most developed countries, most notably the United States, businesses and individuals do not expect the government to intervene in innovation strategies and/or they fail to value government's ability to play a productive role in such efforts. Numerous historical examples identify problems caused by government involvement in innovation strategies. The case of European and Japanese governmental efforts in the development of high-definition television offers one example. Strong government intervention to control the standards for high-definition television in these markets resulted in long-term economic damage to the successful deployment of such technology (Pelkmans and Beuter 1987).

Most developed countries do not expect the government to intervene in innovation strategies

A second school of thought concerning national innovation policies is the systemic or evolutionary-structuralist perspective. This perspective recognizes that, besides market failure, there may be systemic and institutional failures in national innovation policies (Lundvall and Borras 2005). Such a perspective may be highly appropriate for a country such as China. Systemic or evolutionary-structuralist policies expect that the government will address, coordinate, and link systemic innovation needs. Governmental resources can be expected to provide the resources that private enterprises cannot for the development of strategic new industries in developing countries (Cimoli, Dosi, and Stiglitz 2009; Mei 2009).

The third school of thought in this area is interventionism. This perspective also has a long history. In early 1900s List (1928) held that the "visible hand," that is the nation or state, should play an important role in a country's competitiveness. This principle has frequently been adopted by developing countries attempting to "catch up" to contemporary global standards. The rise of Japan and the "Four Tigers of Asia" (Hong Kong, Singapore, South Korea, and Taiwan) all benefited from greater or lesser degrees of governmental involvement in industry (Freeman 1987; Okimoto 1989).

The general success of these five economies supports the argument that indigenous industries still in the early phases of their development require governmental protection from the competition of companies from developed countries. Japan, South Korea, and Taiwan all used national technology and innovation policies to protect specific industries (Cusmano 1985). Mowery (1995) argues that, when properly designed and implemented, such policies are beneficial for the development of new industrial technologies.

Even after 2001, when China became a member of the WTO, this perspective remains popular in China (Gao 2010). Many scholars continue to use these histories in their arguments supporting China's current indigenous innovation strategy (Lu and Feng 2004).

And even in the United States, when evaluating the commercialization of government-sponsored "Small Business Innovation Research" projects, Link and Scott (2010) concluded that governments can successfully act as entrepreneurs by redirecting research and development resources toward the development of technologies that the market alone would otherwise not have developed. In such instances the role of government in "organizing, coordinating, and allocating scarce resources among competing users" is emphasized (Link and Scott 2010, 601).

Jong (2009) singled out three keys to the successful development of Germany's biotech industry: access to finance, professional management teams, and strong inter-enterprise relations.

David (1991) added that focusing on the development of "general purpose technology" is a valuable concept that can establish "hot" areas for private research—but only if public-policy planners can accurately identify such general purpose technologies. In the United States, for example, the information technology industry initially received substantial funding support for basic research, with national defense being the intended major beneficiary.

However, government support has failed to generate equal success in many other economic/technologic areas. In these other areas there was an absence of a strong link between public research and development spending and a broad political support for such government initiatives (Mowery 2006). Populations in free-market countries largely do not trust national industrial policies because they believe that governments cannot improve upon the efficiencies of a free market.

"Catching up" to contemporary global standards is frequently the rationale for the development of interventionist approaches in developing countries. There is a persistent belief that government involvement is needed to narrow the gap between the developed and the developing countries. Enterprises in developing countries are almost invariably weaker than their counterparts in developed countries in terms of technologic capabilities. Countries actively attempting to "catch up" may generate national efforts to enter into promising specific industries using new technologies (Lundvall and Borras 2005, 609). Such industries may be identified as "strategic technologies" (Perroux 1961).

Particularly following the recent financial crisis, interventionist national innovation policies have been emphasized by numerous countries. Countries including both China and the United States adopted new policies supporting emerging industries to stimulate demand and address the future challenges for energy and resources.

History demonstrates multiple options for government policies promoting innovation. The United States and other Western countries have shown that laissez-faire innovation policies can be successful in developed countries. Where, as in many developing countries, the market system is not as well organized, interventionist innovation policies remain popular.

> ***Where the market system is not as well organized, interventionist innovation policies remain popular***

Despite significant government controls, China has largely developed a market-driven economic system since the 1990s. In establishing its current indigenous innovation strategy China adopted an interventionist policy for national innovation. We need to know if, in a transition economy in a world of globalization, global market forces will allow countries such as China to be successful with such an innovation strategy.

Indigenous Innovation in China

The Chinese innovation strategy that emerged beginning in the 1950s was heavily influenced by the Soviet model of that time. Both governments coordinated national innovation activity and established well-defined divisions of labor in innovation. Scientific and technologic innovation efforts were actively separated from industrial efforts. The transfer to enterprises, especially large SOEs, of new technologies developed in research and development institutes was tightly controlled by the government.

Especially given this background, key activities in innovation systems must first be identified to evaluate the performance of any national innovation strategy. Based on the creation, diffusion, and exploitation of technology innovation, Liu and White (2001) compiled a list of five fundamental activities in this process: 1) research and development, 2) production development, 3) end use, 4) education, and 5) linkage. Edquist (2005) later listed ten key activities as being most important in defining systems of innovation. Edquist's list included competence building, financing, formation of new-product markets, incubation, networking, and research and development.

China's 2006 national indigenous innovation strategy called for increased research and development to reduce reliance on foreign technology.

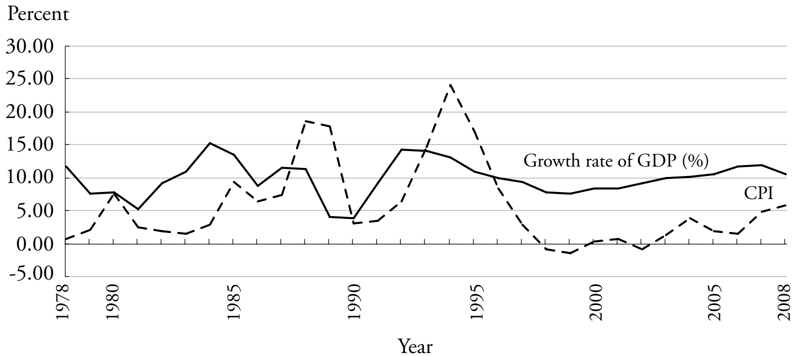
A key question for any innovation strategy involves identifying where the markets may be for any given new technology. In the past, China had had an exceptionally large domestic market but a low technologic capability. Thus, there had been an implicit strategy of trading domestic market share for new foreign technology. Market share in the Chinese marketplace had been ceded to multinational enterprises in exchange for the transfer to Chinese enterprises of some of the technology of these multinational enterprises. During the 1990s this strategy proved to be very effective. China's high-speed rail projects provide one example. To have their bids for work on these projects accepted, multinational enterprises were required to transfer technology to Chinese enterprises (Cheng and Liu 2011).

Since 2006 China's indigenous innovation strategy has changed to use public procurement as one of the main drivers for indigenous innovation and Chinese domestic enterprises have taken on the task of incubating new technologies.

China is currently one of the fastest growing economies in the world. After thirty years of economic opening and reform, China has established a unique economic system with a China-specific enterprise structure. This system has proven very effective in mobilizing national resources to promote economic performance.

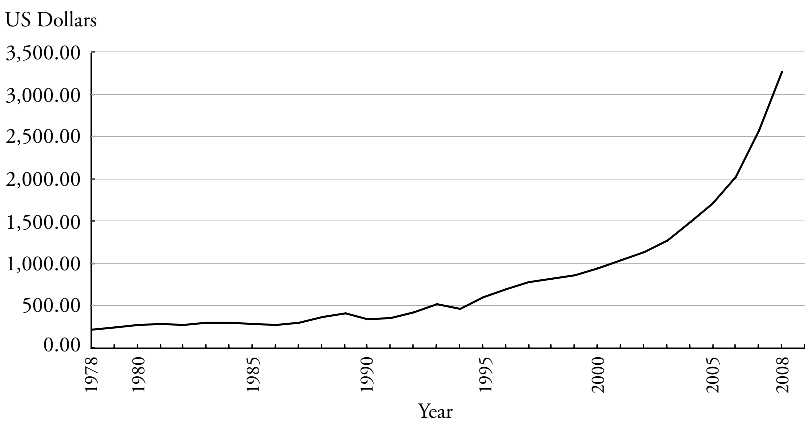
Prior to the implementation of China's 2006 indigenous innovation strategy the Chinese economy had demonstrated more than twenty years of high economic growth (Figure 1). Chinese per capita GDP had reached over US$2,000 by 2006 (Figure 2) and US$3,268 by 2008.

Figure 1. Growth Rate of China's GDP, 1978–2008



Source: Online database of the National Bureau of Statistics of China www.stats.gov.cn/
Note: CPI = consumer price index

Figure 2. China's Per Capita GDP, 1978–2008



Source: Online database of the National Bureau of Statistics of China www.stats.gov.cn/

Unfortunately, despite this outstanding economic growth, China's capability for technologic innovation had not developed as successfully. During this period China's economic growth had been strongly dependent on foreign technology and capital supply. Poor innovation capability at the industrial-enterprise level resulted in China's economy being limited by low profit margins. High costs driven by payments for royalty fees for licensed technology and other intellectual property rights trapped the Chinese economy. This was especially an issue in such key industries as computer software, engines, machine tools, and microchips. In all of these industries China is still heavily reliant on a continuing supply of foreign technology.

Many academics (e.g., Liu 2005; Lu and Feng 2004) and government officials believe this situation demonstrates the failure of China's earlier strategy of trading market share for new technology. The earlier strategy resulted in multinational enterprises acquiring large shares of the domestic Chinese market. Following this market reallocation, Chinese enterprises were less successful in acquiring new technology (Lu and Feng 2004). However, other researchers (e.g., Wang and Lei 2008) do not agree with these conclusions.

The earlier strategy resulted in multinational enterprises acquiring large shares of the domestic Chinese market

Increasing the integration and productivity of the Chinese innovation system remains a major challenge for China's future economic development. China must shift from purchasing foreign technology to generating more domestic research and development to make its economy more innovation driven.

At the beginning of the twenty-first century China chose to address the contrast of having succeeded with rapid economic growth while still lacking substantive innovation capability. Continuing their search for sustainable development while facing their future shortage of natural resources, Chinese authorities launched their new indigenous innovation strategy. The goal of China's new indigenous innovation strategy is to significantly improve the capability of Chinese science and technology by 2020. By converting domestic enterprises from cost-limited to innovation-driven institutions, decreasing reliance on foreign technology, mastering cutting-edge industrial technology, and promoting economic and social development, the goal is to make China one of the world's recognized innovative countries

(State Council of China 2006). In 2006, China marked a major turning point as the government first began implementing this long-range science-and-technology development program.

Deep-rooted challenges remain, however, before China truly becomes an innovative country.

First, China's recent economic growth has been strongly dependent on foreign technology and foreign direct investment. Foreign-invested enterprises have accounted for more than 85 percent of all of China's high-tech exports since 2000 (NBS and NDRC 2006). There has been, in recent years, increasing frustration among some academics and government officials that the earlier "market share for new technology" exchange policy did not generate the technology transfer from foreign enterprises to Chinese enterprises that had been expected.

In part shaped by the historical lessons from the 1960s surrounding China's acquisition of nuclear weaponry, the Chinese government believes that only an ability to develop their own technology will provide China true economic sovereignty.

Second, while Chinese enterprises, largely fueled by low labor costs, made China the manufacturing exporter to the world, Chinese enterprises realized only limited profit margins from these exports. As they had achieved only very limited innovation success during this time, Chinese domestic enterprises were frequently forced to pay multinational enterprises high royalty fees for intellectual property rights.

Chinese enterprises have been granted relatively few patents by the United States. In 2008 there were only 2,653 US patents granted to Chinese enterprises while, in the same year, South Korea saw 8,924 US patents granted to its domestic enterprises (Table 1). Obviously far more active creation and innovation of intellectual property, through a vastly improved domestic knowledge base, is badly needed in China.

Third, China's last twenty years of rapid economic growth cannot be sustained into the future without an improved innovation strategy. This concern has been addressed multiple times in speeches by Premier Wen (Wen 2006). For future success, China needs more energy-efficient and environmentally friendly technologies, new management skills, and new organizational practices to ensure sustainable growth.

Table 1. US Patents Granted to Enterprises from China, Japan, South Korea, and Taiwan, 1995–2008

Year	China	Japan	South Korea	Taiwan
1995	91	23,139	1,265	2,142
1996	78	24,355	1,603	2,477
1997	103	24,498	2,027	2,678
1998	133	32,543	3,427	3,911
1999	172	32,928	3,741	4,664
2000	274	33,387	3,560	5,976
2001	472	35,417	3,849	6,685
2002	626	36,860	4,100	6,883
2003	724	37,744	4,246	6,846
2004	951	37,568	4,769	7,435
2005	963	32,243	4,696	6,172
2006	1,621	39,954	6,634	8,241
2007	1,827	36,452	7,465	7,759
2008	2,653	37,250	8,924	8,126

Source: Online database of the United States Patent and Trademark Office, www.uspto.gov/.

These concerns have driven the Chinese government to strengthen China's "indigenous" innovation. The government has taken the leadership of China's innovation systems. No longer will foreign direct investment be allowed to play the leading role in China's technological progress.

Specific goals of the 2006 indigenous innovation strategy are to: increase research and development funding to 2 percent of GDP in 2010 and 2.5 percent of GDP by 2020, make innovation in science and technology the key factor driving GDP growth and to see this focus contribute about 60 percent of future GDP growth, decrease the dependence on foreign technology to less than 30 percent (computed as the ratio of expenditures on imported technology to expenditures on domestic research and development; in 2004 this ratio was estimated at 56 percent), and, finally, to be among the top five nations worldwide in the number of invention patents granted and in the number of international citations of scientific papers (State Council of China 2006).

According to Aschhoff and Sofka (2009), innovation is generally driven by four elements of public policy: 1) public procurement, 2) regulation, 3) universities and government-led research institutes, and 4) government research and development funding. China's indigenous innovation strategy has used additional elements of government policy in the nation's quest to achieve the goal of becoming an innovative country by 2010. The advantages and limits of these various policies are outlined below.

First the government plan is to increase, by 2020, research and development funding from the current 1.49 percent of GDP to 2.5 percent of GDP. As overall GDP growth is projected to continue at its current rate, increasing research and development investment as a percentage of the growing GDP mandates a massive increase of funding in absolute terms.

Increasing research and development investment as a percentage of GDP mandates a massive increase of funding

Second, government fiscal policies now prioritize the promotion, at enterprise levels, of innovation capability. Most relevant are the changes to government technology-procurement policies. These changes are critically important to the promotion of indigenous innovation in China. These policies follow from the lessons of the best practices of South Korea and the United States.

Technology procurement by the government is economically significant in today's China—but the policy use of such procurement as an innovation driver is relatively new. The earlier priority in Chinese public procurement was to minimize costs, not to promote indigenous innovation. Under the 2006 policy, government agencies began actively supporting innovative Chinese enterprises by procuring their goods and/or services even if, when compared with goods and/or services from foreign enterprises, there were quality or cost issues (State Council of China 2006).

Third, the government is more effectively establishing standards and enforcing intellectual property rights as an element of these new policies promoting innovation. These efforts, in the eyes of the international community, serve to legitimize Chinese intellectual property rights.

While the development of the TD-SCDMA technology (further discussed below) as an alternative "third generation" (3G) technology standard for telecommunications began before 2006, it was around that year that the still-immature TD-SCDMA technology encountered serious problems. China's 2006 strategy for indigenous innovation resulted in government support that saved this developing technology, picking it as the national technology standard for 3G.

Fourth, government tax policies now make enterprise research and development funding 150 percent tax deductible, thus generating a significant net subsidy for such funding. Enterprises are also being allowed accelerated depreciation on research and development equipment valued up to 300,000 RMB (US$40,000).

Finally, a new program for government-funded mega-projects is expected to play a key role in linking government objectives with industrial innovation. It is expected that development of the mega-projects, of which there are sixteen, will help China master the core technologies of various strategic industries. Currently commissioned projects include the development of large aircraft, lunar exploration, next-generation broadband wireless mobile telecommunications, next-generation computer central processing units, new drugs and medicines, nuclear reactors, and more.

Government-sponsored research consortia (collaborations involving leading companies and universities and government-led research institutes) for these projects have been established for improved organization and increased efficiency. Government-sponsored research consortia are far from being a Chinese invention. They have a significant history of use by Japan, South Korea, and the United States in the 1980s and 1990s.

Such consortia are expected to improve critical industrial technology. To achieve this goal the government acts as the central coordinator. Domestic enterprises and universities and government-led research institutes work with government funding to form research and development teams focusing on specific elements of the mega-projects. Industrial competitors may work together in the same consortia.

Following the decentralization of central government controls, participation in the new innovation systems by elements of regional governments has become increasingly significant. Though the national government leads in establishing new policies, the implementation of these national policies now largely depends upon the regional governments.

Many regional governments have developed their own systems for supporting industrial development and innovation. Benefits to regional governments for promoting innovation range from improving the local economy by growing local industry to increased political capital gained by successfully responding to requests from the central government. Some regional governments have, unfortunately, chosen to do little or nothing in this area.

Current research and development funding by regional governments exceeds that from the central government (MOST and NBS 2009). As government-supported innovation requires the risk of a capital investment, however, only governments from wealthier regions have so far demonstrated both the capability and interest to make such investments. Regional governments from wealthier regions such as Guangdong, Jiangsu, Shandong, Shanghai, and Zhejiang are among those that have been most active in supporting indigenous innovation. Based on the research of Liu (2010b), these governments are the most supportive of innovation efforts. These regions benefit from their innovation efforts through the renewal and upgrading of their local industries as well as through direct subsidies provided by the central government.

Only governments from wealthier regions have demonstrated the capability and interest to invest in innovation

Especially in southern China, many of China's emerging strategic industries were first introduced by regional governments. For example, the Jiangsu "Suntech" photovoltaic industry began in 2001 without the involvement of the central government. More than seventeen regions now include photovoltaics among their key industries. Many regions have also tried to capture a share of the wind-power industry. In 2008 the NDRC established a program to achieve a wind-power capacity of 10 million kW by 2010. Wind-power capacity actually reached 12.27 million kW by 2010.

Jiangsu province, in particular, has generated many innovation initiatives. These include the establishment of new research institutes, funding for attracting spin-off industries, global talent searches for new industries, and special funding for innovation (Liu 2010b).

In the regions noted above, private enterprises now dominate innovation activity. They are currently the main drivers of the Chinese innovation system (see Table 2). Private enterprises are usually active in innovation in areas not being addressed by SOEs and/or in areas that are new to China. Capital-intensive sectors—such as the automobile, banking, petroleum, and utility industries—remain protected by the central government so private enterprises find high barriers to entry. In many other industries—including clothing/garments, food and beverage, household electrical appliances, information technology, light industry, machinery, and toys—market competition, as it does in other market economies, drives private enterprises to innovate.

Table 2. Top Six Chinese Regions in Research and Development Funding for Enterprises (2009)

Region	Research and Development Funding by Enterprises (US$, Billions)	Total Research and Development Funding (US$, Billions)
Jiangsu	8.36	10.28
Guangdong	8.08	9.56
Shandong	6.69	7.61
Zhejiang	4.83	5.84
Shanghai	3.45	6.19
Beijing	1.67	9.79
All regions	55.28	84.94

Source: National Research and Development Survey http://www.most.gov.cn/.

Regional governments largely define their own innovation interests. Political commitments by regional governments to economic decisions made by the central government do, however, aid in gaining investment from the central government, which still controls most substantial funding for mega-projects. Even the less-wealthy western regions, regardless of their industrial capability and level of development, generally generate some innovation initiative whenever the central government identifies such industries as biology, new energy, next-generation information technology, or others as key national targets.

Regional governments will also base innovation decisions on their perceived local competitive advantages. Already-developed regions will usually make more aggressive additional investments in innovation and new industries. Notably, Jiangsu province invests more than other provinces in subsidizing regional enterprises in new industry and research and development.

China's new indigenous innovation strategy reflects a major turning point for national policy making; a wholly new policy paradigm. First, relative to previous policies, the new policies are heavily demand-driven. Second, the new policies promote innovation in a more systematic fashion. All aspects of economic development—from research and development to the creation of a supply chain to product manufacturing to early market incubation—are addressed. Third, innovation policy has now been upgraded to the status of a national economic policy, a higher level than was traditional for science and technology policies. And fourth, the government is attempting to use indigenous innovation to balance the domestic-market demand against the export-market demand; the development of domestic innovation capability is now being prioritized over the acquisition of foreign technology.

How China's Innovation Systems are Transformed by the New Strategy

Objectives and Policy Tools

Research and Development Funding

The central government has, in accordance with the 2006 policy, accelerated funding for research and development. Additional funding committed to research and development is the primary method by which China expects to upgrade its innovation capability. Table 3 demonstrates that the central government is, especially after 2005, significantly increasing funding for research and development. In 2007 China ranked sixth in the world in terms of absolute research and development funding (NBS and MOST 2009). Chinese research and development funding, as a percentage of the national GDP, reached 1.7 percent in 2009, the highest level in Chinese history. Both figures denote significant benchmarks for Chinese innovation.

Table 3. National Research and Development Funding, 2001–2009

	2001	2002	2003	2004	2005	2006	2007	2008	2009
National Research and Development Funding (US$, Billions)	12.60	15.56	18.60	23.74	30.36	38.50	50.82	66.23	86.60
Research and Development Funding/GDP (percent)	0.95	1.07	1.13	1.23	1.34	1.42	1.49	1.52	1.70

Source: Online database of MOST, www.most.gov.cn.
National Bureau of Statistics (NBS), Ministry of Science and Technology (MOST), and Ministry of Finance (MOF) *Bulletin of National Science and Technology Funding*, 2009.

Specifically targeted national science-and-technology programs established by the Ministry of Science and Technology (MOST) have been among the most important efforts taken to realize the national innovation strategy. Table 4 provides a brief overview of the major programs established by the ministry.

Among these science-and-technology programs the national high-tech program (identified as program "863"), launched in 1986 and focusing on the specific goal of bringing Chinese high technology up to contemporary global standards, has been the priority. Over 1995–2005 about US$4.9 billion was spent through program "863" on the development of civil technology. Most regional high-technology industries owe at least part of their development to support from this program. Program "863" planted the seeds for China's high-tech industry and continues to be deeply involved with the development of various high-tech zones in China.

Table 4. National Science and Technology Program Funding (US$, Millions), 2001–2008

	2001	2002	2003	2004	2005	2006	2007	2008
"973" Basic Research	71.2	82.8	96.6	108.3	121.8	173.6	225.5	275.4
Key Technologies Research and Development Program	127.2	161.6	162.5	195.0	201.3	384.6	745.4	734.8
"863" High-tech Program	301.9	305.9	1,147.8	1,122.3	1,409.6	–	–	–
National Key Experimental Laboratories Program	15.7	15.7	15.7	15.7	16.6	27.7	21.9	23.3
Innovation Fund for Small and Medium Enterprises (SMEs)	94.6	65.2	80.2	99.9	122.5	108.1	172.1	211.6

Source: MOST, *China Science and Technology Development Report*, 2006. China S&T Literature Press.

Mega-Projects

In 2006 sixteen mega-projects were identified by the central government. A few years later these projects served to substantially mitigate the effects of the global financial crisis on China. The projects were expected, according to the original plan, to start one by one at such times as market conditions for the specific technologies were believed mature. The central government had planned to invest US$100 billion in these sixteen mega-projects between 2006 and 2020.

These mega-projects substantially mitigated the effects of the global financial crisis on China

However, the 2007 global financial crisis spurred the government to begin all sixteen projects as quickly as possible. As might be expected, particularly given the accelerated scheduling, some projects are developing more successfully than others. Among the more successful is the large-airplane mega-project. This appears to be progressing much more quickly than predicted and has been reported to already have over one hundred orders for the new plane (Caijing.com.cn 2010).

Standards and Intellectual Property Rights

Standards and intellectual property rights are considered the keys to unlocking the potential of innovative markets and strengthening the Chinese economy. Ernst (2011, chapter 2) documents that the setting of accepted standards as an innovation policy is relatively new to China and that establishing national and/or international standards has only been rarely addressed.

One example is the TD-SCDMA telecommunications standard, which was established by the central government to promote innovation in the telecommunications industry. In 2003 the central government passed a number of measures designed to support the development of TD-SCDMA as one element of indigenous innovation. A review of this technology may now serve as a case study on the success of the indigenous innovation strategy.

The TD-SCDMA standard was proposed by the DaTang Telecom Technology and Industry Group on behalf of the Chinese government in May 2000 and was approved by the International Telecommunication Union as an acceptable 3G mobile telecommunications standard. This was a major milestone for Chinese innovation. At the time TD-SCDMA was still a very new technology when compared to the previously approved Code-Division Multiple Access 2000 (CDMA2000) and Wideband Code Division Multiple Access (WCDMA) standards. However, the potentially significant and exceptionally large domestic Chinese market for such a standard generated considerable support within the approval process. In 2002 central government support for the new standard moved beyond funding for research and development. Government agencies, most notably MII, MOST, and NDRC, began to actively advocate the commercialization of TD-SCDMA technology.

By funding such efforts as the "863" and "973" programs the central government had, in the past, provided generous capital for research and development of technological innovation. According to authoritative Chinese media and government agencies, since the late 1990s over RMB 1.2 billion (US$150 million) of special funds had been provided by MII, MOST, and NDRC to develop TD-SCDMA (Zhan and Tan 2010). Even before 2006 the Chinese government also created research consortia or TD-SCDMA alliances so that more companies could participate in and share the benefits of the new technology. Lastly, but extremely significantly, the central government allocated the 155 MHz broadcast frequency for future use by TD-SCDMA technology. All these actions clearly signaled that TD-SCDMA technology was expected to be the authorized technology for future 3G telecommunications markets.

With the adoption of the 2006–2020 Medium- and Long-Term National Science and Technology Development Plan, domestic innovation became an official priority. The central government identified the TD-SCDMA standard as an important indigenous innovation. They actively supported the development of this technology through both funding and government policies.

Although the technology still faces many uncertainties, the current economic climate is benefitting those within the 3G market attempting to see TD-SCDMA technology gain domestic Chinese market share against the pre-existing technologies of multinational enterprises. The Chinese central government began in 2006 to use the power of the marketplace to support the use of the TD-SCDMA standard. The government slowed the licensing process for 3G technology, giving TD-SCDMA more developmental time. They also allowed China Mobile, an SOE, to capitalize and establish TD-SCDMA networks and perform pre-commercial operations in eight Chinese cities (Liu 2008; Table 5).

Table 5. Chinese Standard Initiative

Standard	Motivations	Promoters	Milestones
TD-SCDMA	Lower royalty fees Improve China's competitiveness	DaTang Telecom TD-SCDMA Industry Alliance	Initiated by the central government in 1998 Approved as an international standard in 2000 Approved as a national compulsory standard in 2006

Source: Suttmeier, Richard P., Xiangkui Yao, and Alex Zixiang Tan. 2006. *Standards of Power? Technology, Institutions, and Politics in the Development of China's National Standards Strategy*, NBR Special Report, No.10, June. Seattle: The National Bureau of Asian Research.

TD-SCDMA is a newer standard, developed after both CDMA2000 and WCDMA were the commonly used 3G standards throughout the world. When TD-SCDMA was first introduced even domestic Chinese enterprises were concerned that TD-SCDMA was not adequately developed.

In 2006, however, TD-SCDMA became the compulsory Chinese national standard and China Mobile, as China's largest SOE working with 3G technology, was given the responsibility to operate the standard. TD-SCDMA is now considered a national success story in the information technology industry.

TD-SCDMA is now considered a national success story

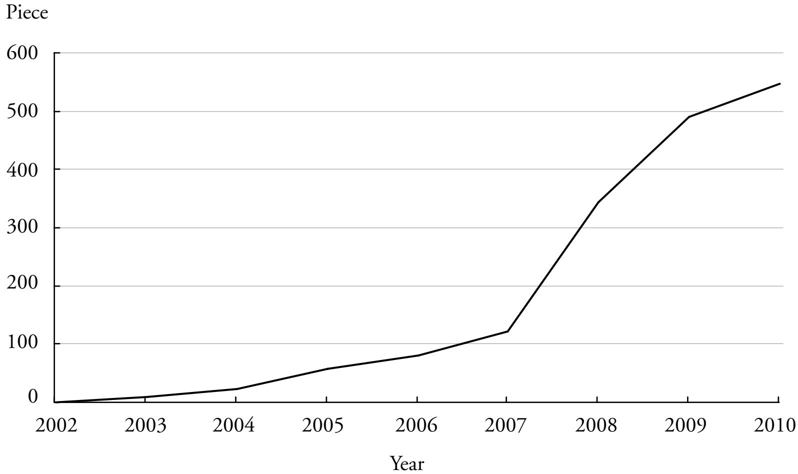
This strong governmental support has created an ideal market and industrial environment for the continuing development of TD-SCDMA technology. Companies developing telecommunications systems equipment (e.g., DaTang and Siemens), chip designers (e.g., DaTang, MediaTek, Spreadtrum Communications, and T3G Technology), mobile-phone handset manufacturers (e.g., DaTang, Dopod, and Soutec), service providers (e.g., China Mobile), and testing and instrument companies (e.g., ZCTT and Zhongyou) are all now active in the TD-SCDMA industry (see Table 6 and Figure 3).

Table 6. Chinese Enterprises Active in the TD-SCDMA Industry Alliance, 2002–2008

	2002	**2003**	**2005**	**2006**	**2007**	**2008**
System equipment manufacturers	4	5	10	12	16	21
Chip designers	1	5	5	6	7	9
Testing and instrument companies	0	0	2	3	4	5
Mobile-phone handset makers	3	5	11	11	12	24
Operators	1	1	2	2	2	8

Source: Authors' calculations from multiple sources.

Figure 3. Aggregated Invention Patents Granted to Chinese Companies for TD-SCDMA Technology, 2002–2010



Source: Authors' calculations from multiple sources.

In the 3G technology industry, where TD-SCDMA is only one option, the value chain is highly complex. Companies from China and from other developed countries actively compete for global market share. The domestic Chinese market for 3G services is growing. However, while it is growing, the market share for 3G services within the overall Chinese telecommunications sector remains relatively small. As of the end of March 2010 it was estimated that, worldwide, there were 7.7 million TD-SCDMA users and a combined total of 11.0 million users for the CDMA2000 and WCDMA standards.[1]

The pace of the adoption of TD-SCDMA technology is affected by multiple factors. Because the 3G industry has a long and complex value chain the Chinese central government cannot organize the entire process of technology development. With handset technology still largely controlled by multinational enterprises, domestic Chinese handset enterprises seeking to make use of TD-SCDMA technology are unable to be fully competitive. Many multinational enterprises appear to be waiting for some significant market opportunity to adopt TD-SCDMA technology, which is a major factor in why this standard has not grown more quickly. As noted above, as Chinese domestic enterprises are generally weak in the handset sector, pricing for TD-SCDMA technology 3G handsets remains much higher than competitive products from multinational enterprises. And as provider networks supporting TD-SCDMA technology are still in construction, service fees are also higher.

While the support of the Chinese central government has been critical to the current success of TD-SCDMA technology it has not been without sometimes significant negative impacts on the Chinese telecommunications industry. When the Chinese government delayed licensing domestic 3G services until TD-SCDMA technology was more fully developed, they delayed the introduction of any 3G standards in China for several years. While DaTang has become the innovation hero of many domestic enterprises, the central government has not allowed DaTang, as a domestic SOE, to form joint ventures with multinational enterprises to pave the way for DaTang increasing its international efforts.

China Mobile and other key partner enterprises are now looking toward transitioning to Long Term Evolution (LTE) technology as an interim precursor to full "fourth generation" (4G) technology. The speed of this next transition will certainly be affected by future government policies.

Public Procurement

As noted above, since 2006 China's indigenous innovation strategy has changed to use public procurement as one of the main drivers for indigenous innovation. Before implementing the current policy, Chinese experts studied and learned much from the experiences of South Korea and the United States. And, while Japan's Ministry of International Trade and Industry never explicitly implemented the use of public procurement policies to support Japan's industries (Okimoto 1989), Chinese experts also studied how the Japanese economy and its domestic innovation did, in fact, benefit from public procurement policies during Japan's development in the 1980s.

The key concept of these policies is to make use of public funding to promote the development of innovative domestic products. Decisions concerning which specific cases will benefit from the implementation of such a policy, however, must clearly be made by the government. The question of which innovative domestic products are to be supported must be addressed.

Government documents identify the key requirements defining domestic enterprises producing indigenous domestic products: they have a Chinese brand, use Chinese intellectual property, and have at least 51 percent Chinese ownership. Additionally, for key projects financed by regional governments, the State Council requires that made-in-China equipment should account for at least 60 percent of the total value of equipment purchases.[2]

Enhancing Enterprise Capabilities

Without private enterprise, government investment in universities and research institutes has not generally been successful

China's indigenous innovation policy was based on historical observations that private enterprises have consistently played an important role in technologic innovation. Without the involvement of private enterprises, government investment in universities and government-led research institutes has not generally been particularly successful.

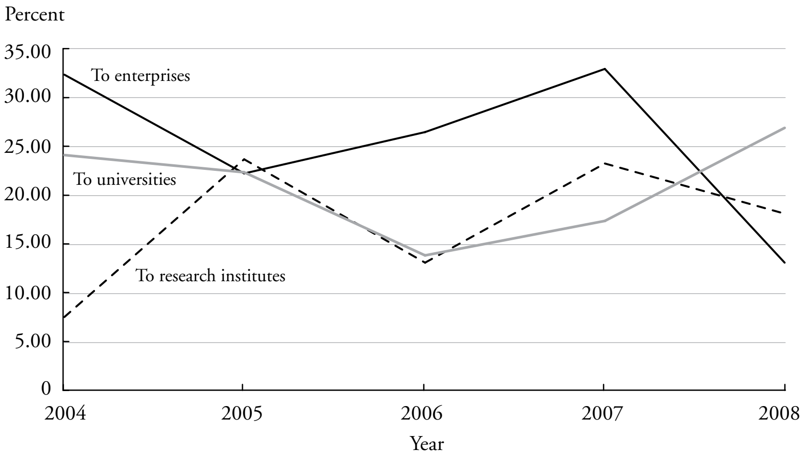
Enterprise-led innovation systems had been proposed for many years. However, universities and government-led research institutes have historically had much stronger lobbying capabilities than private enterprises so, in the past, most national research and development projects went to these universities and government-led research institutes.

Under the new innovation policy most mega-projects have used research consortia in which private enterprises have played far more prominent roles. In the "High-Performance Digital Machine Tools" mega-project, coordinated by MII, for example, the main participants include: Beijing First Machine-Tool Group, China Academy of Machinery Science and Technology, China Second Group of Heavy-Machine, Jinan Second Machine-Tool Group, and Xian Jiaotong University.[3] Private enterprises play a dominant role in this research consortium.

Though the absolute amounts were still small, from 2002 to 2007 central government funding for research and development maintained a high rate of growth (see Figure 4). Research and development funding by the central government for private enterprises grew faster than such funding grew for other institutions. In 2007 the central government's research and development subsidy for private enterprises was 46.3

percent higher than in 2006; for universities and government-led research institutes it was, respectively, only 33.2 percent and 28.2 percent higher. This was largely a result of the new policy goal of indigenous innovation; private enterprises now received more funding support for innovations in key industrial technologies. With the new indigenous innovation policy private enterprises began receiving more in direct subsidies from the central government than they had in the past.

Figure 4. Growth Rate of Chinese Central Government Research and Development Funding for Enterprises, Universities, and Government-Led Research Institutes, 2004–2008



Source: Authors' calculations from multiple sources.

The key question that remains to be answered is whether such an increase in government research and development funding will successfully promote private enterprise investment in research and development and innovation.

The new indigenous innovation policy has largely been implemented through a varied combination of strategies. The most significant of these strategies is, arguably, the use of government-led research consortia to cultivate productive environments for innovation in target industries.

Research Consortia

Innovation policies involving government-organized and -supported research consortia were not invented by developing countries. Similar consortia were important elements in the innovation policies of both Japan and the United States during the 1980s. Japan's Ministry of International Trade and Industry succeeded in forming effective research consortia to bring that nation's electronics industry technology up to, and then lead, global standards (Okimoto 1989). At the same time similar efforts in other sectors, such as in the computer industry, were unsuccessful. By the 1990s, faced with multiple failures, these policies were discontinued.

In the United States, David (1991) coined the term "general purpose technology" for a technology that would affect the entire economy. David argued that if public policy planners identify and target such general purpose technologies then support of these technologies will generate significant "hot" fields for private research. In the information technology industry of the 1980s, the US federal government funded basic research and directed the defense sector to purchase the resulting products. As America's defense sector is a large purchaser, those actions helped the nation's information technology industry become the most powerful in the world. As noted above, similar efforts in other fields have failed. Again as noted earlier, Mowery (2006) proposed that in these other areas there was an absence of a strong link between public research and development spending and a broad political support for such government initiatives.

The Chinese central government's implementation of sixteen mega-projects made use of the policy of government-organized and -supported research consortia. Many of these projects operate with coordination from government agencies. Large SOEs or private enterprises serve as the leading elements and universities and government-led research institutes form the research and development team. Final users are also active participants in these consortia. A good example is the mega-project developing next-generation telecommunications technology in which Huawei and ZTE, as well as China Mobile, are all key players in the consortia.

Basic Research

Currently it is generally accepted that basic research is a form of public good—but it is not free (Pavitt 2001). Basic research requires considerable time and investment in the development of equipment, institutions, and human skills to produce significant positive results

(Callon 1994). Government funding for basic research has generated valuable benefits for businesses involved in the information technology and biological industries.

China's government has, at least in the past, been more attentive to short-term return on investments. The government has made fewer investments in areas where the returns might be less certain or require longer terms—as is the case with basic research. The Chinese system has focused on applied projects with little investment in areas with less certainty of results or in long-term development where exploration and experimentation might generate unknown but possibly significant benefits for various industries.

The Chinese system focused on applied projects with little investment in long-term development

Table 7 shows that leading industrialized and emerging countries focus funding more on applied research than on basic research. China still under invests in basic research, despite more than six years of implementing its national indigenous innovation strategy. A nation's basic research relies heavily on government research and development funding. Yet, China's basic research funding accounted for only 5.2 percent of the total 2006 national research and development funding. This was far less than the support for basic research (as percentages of the overall national research and development funding)

Table 7. Funding, by Country, of Basic and Applied Research and Experimental Development (percent)

	China	**USA**	**Japan**	**France**	**Australia**	**Switzer-land**	**Korea**	**Russia**
Type of Research	2006	2004	2003	2003	2002	2000	2003	2003
Basic Research	5.2	18.7	13.3	24.1	24.9	28.0	14.5	15.1
Applied Research	16.8	21.3	22.4	36.2	37.2	35.8	20.8	15.6
Experimental Development	78.0	60.0	64.3	39.7	37.9	36.3	64.7	69.4

Source: China Statistical Yearbook on Science and Technology, 2008.

in Japan (12.65 percent; 2005), Russia (15.1 percent; 2003), South Korea (15.15 percent; 2006), and the United States (18.56 percent; 2006) (NBS and MOST 2009).

For many years funding for basic research made up around 5 percent of the total Chinese research and development support (see Table 8). Following the launch of the indigenous innovation strategy, the percentage of government research and development funding devoted to applied research increased while that devoted to basic research decreased. After 2006, government funding for basic research decreased to 4.7 percent of overall research and development support.

Table 8. Chinese Research and Development Funding by Type of Research, 1995–2008

	Basic Research (percent)	Applied Research (percent)	Experimental Development (percent)	percent of GDP
1995	5.18	26.39	68.43	0.57
1996	5.00	24.51	70.49	0.57
1997	5.39	26.02	68.60	0.64
1998	5.25	22.61	72.13	0.65
1999	4.99	22.32	72.68	0.76
2000	5.22	16.96	77.82	0.90
2001	5.33	17.73	76.93	0.95
2002	5.73	19.16	75.12	1.07
2003	5.69	20.23	74.08	1.13
2004	5.96	20.37	73.67	1.23
2005	5.36	17.70	76.95	1.34
2006	5.19	16.28	78.53	1.42
2007	4.70	13.29	82.01	1.49
2008*	4.70	12.6	82.7	1.70

Source: China Statistical Yearbook on Science and Technology, 2009.
* National Research and Development Survey, 2009, http://www.most.gov.cn/.

The research and development activities of most Chinese private enterprises focus on short-term experimental development yielding rapid cost reductions or other immediate benefits. Finding ways to increase government funding for basic research has now become a critical issue.

Impact of the Indigenous Innovation Strategy on Universities and Government-Led Research Institutes

Poor innovation performance in China is reflected in the relatively low number of radical innovations at the enterprise level (Liu 2010a). The enterprise level sees significantly more incremental innovation than breakthrough innovation. It is generally accepted that increased funding for basic research would aid China in increasing its breakthrough innovations. This, in turn, would promote China's standing as an innovative nation and market leader in multiple industries.

Since 2004 China's research and development funding has increased annually by over 20 percent. China's 2008 level of research and development funding, as a percentage of the national GDP, was still, however, only equal to the average percentage for such funding in developing countries. In 2008 China's research and development funding reached 1.52 percent of GDP, which was still significantly lower than the 2.68 percent of national GDP devoted to US research and development efforts in 2007 (NBS and MOST 2009).

China's research and development funding structure (see Table 9) appears reasonable—however the government's support for basic research has remained relatively low. As noted earlier, with the implementation of the indigenous innovation strategy, government support has focused more on applied research than on basic research. In 2008 total funding for applied research and experimental development reached US$63.3 billion while the total funding for basic research was only US$3.2 billion (NBS and MOST 2009).

Trends in national scientific capability, as measured by the Science Citation Index (SCI) for science and technology papers, have followed the increases in government research and development funding. SCI papers published in China tripled from 2003 to 2008 (see Table 10). In 2008 China became second only to the United States in the number of science and technology papers indexed by the Index to Scientific and Technical Proceedings (ISTP) and the

Table 9. International Research and Development Funding by Type of Research (percent)

	China	USA	Japan	France	Australia	Switzer-land	Korea	Russia
Types of Research	2007	2006	2005	2005	2004	2004	2006	2003
Basic Research	4.70	18.56	12.65	23.70	23.17	28.70	15.15	15.10
Applied Research	13.28	23.12	22.18	38.99	38.14	33.32	19.86	15.60
Experimental Development	82.01	58.31	65.17	37.31	38.69	37.98	64.99	69.40

Source: China Statistical Yearbook on Science and Technology, 2009.

Table 10. Chinese Science and Technology Publications (x 10,000) Indexed by the Engineering Index (EI), Index to Scientific and Technical Proceedings (ISTP), and Science Citation Index (SCI), 2003–2008

	2003	2004	2005	2006	2007	2008
Total	9.3	11.1	15.3	17.2	20.8	27.1
EI	2.5	3.4	5.4	6.5	7.6	8.9
ISTP	1.9	2.0	3.1	3.5	4.3	6.5
SCI	5.0	5.7	6.8	7.1	8.9	11.7

Source: China Statistical Yearbook on Science and Technology, 2009.

SCI. In 2003 Chinese science and technology papers indexed by the Engineering Index (EI), ISTP, and SCI, had ranked only fifth, sixth, and sixth, respectively.

However, the citations of Chinese science and technology papers in the Essential Science Indicators (ESI) listing ranks only tenth (see Table 11). This indicates that continuing to improve the quality of Chinese science and technology papers must remain a long-term goal.

Table 11. Top Ten Countries for Science and Technology Publication Citations as Identified by Essential Science Indicators (ESI; January 1998–August 31, 2008)

Country (Area)	Rank	# of Citations	# of Papers	Citations Per Paper
USA	1	42,269,694	2,959,661	14
Germany	2	8,787,460	766,146	11
UK	3	8,768,475	678,686	13
Japan	4	7,201,664	796,807	9
France	5	5,933,187	548,279	11
Canada	6	4,837,825	414,248	12
Italy	7	4,044,512	394,428	10
Netherlands	8	3,148,005	231,682	14
Australia	9	2,784,738	267,134	10
China	10	2,646,085	573,486	5

Source: http://science.thomsonreuters.com.cn Essential Science Indicators, covering the ten-year-and-eight-month period of January 1998–August 31, 2008.

How Enterprises Respond to Indigenous Innovation

China's central government has aggressively promoted indigenous innovation through new policies and the provision of additional resources. However the most significant evaluation criteria for the success of this strategy lies in the responses from private enterprises.

"Innovation," for most private enterprises, is an economic or technologic term rather than a political one. Such efforts are driven by Adam Smith's earlier-noted "invisible hand" of the free market. Thus indigenous innovation must produce economic benefits to effect changes in enterprise behavior. Following is a discussion

Indigenous innovation must produce economic benefits to effect changes in enterprise behavior

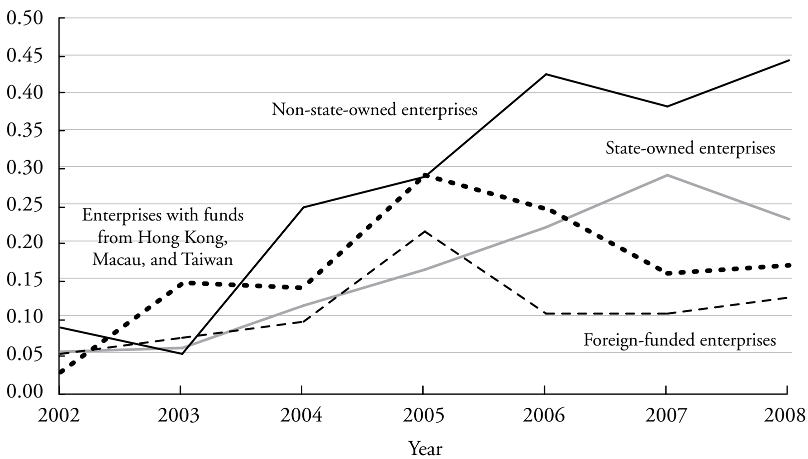
of the effects noted on Chinese domestic enterprises by the changes driven by the new indigenous innovation strategy.

Private enterprises balance generating research and development for indigenous innovation against the purchase of other, often foreign, technologies. Even with the new indigenous innovation strategy, securing direct government subsidies for research and development remains very difficult for most private enterprises and only a small number of these enterprises actually receive such support. Many enterprises continue, as before, to prefer to purchase technology, or form alliances for research and development, rather than individually invest in research and development.

Some of China's leading private enterprises, such as Huawei, have publicly stated that they would prefer a more open innovation policy where they would be allowed to easily cooperate with international firms. They believe they would be more successful in innovation by working with the benefits of an existing technologic knowledge base rather than being limited by a fully indigenous innovation strategy in which they must build technologies from scratch.[4]

Figure 5 shows that Chinese enterprises are now spending more money to assimilate imported technology than to buy it. This indicates

Figure 5. Ratio of Expenditure to Assimilate Imported Technology to Expenditure to Purchase that Technology 2002–2008



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2009.

that domestic enterprises are now more concerned with moving beyond the use of imported technology rather than simply expanding production capability based solely on the use of imported technology.

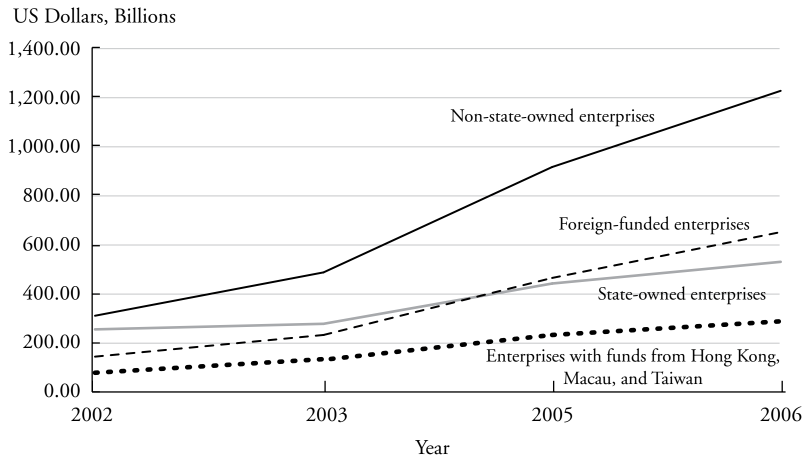
This may explain why the ratios for domestic enterprises are higher than those for foreign-invested enterprises; ratios for non-SOEs are higher than those for SOEs, and ratios for advanced-technology foreign-invested enterprises are the lowest. In 2008 the average proportion for state-owned enterprises was 0.23:1. Non-SOEs reached a ratio of 0.44:1; Hong Kong–, Macao-, and Taiwan-invested enterprises averaged 0.17:1; and foreign-invested enterprises reached 0.13:1. This proportion for SOEs has increased in recent years but, in general, the ratio for SOEs is still low relative to the much faster growth trend for non-SOEs.

Private enterprises, which operate in competitive markets, now lead in building capability for innovation. Various factors that impact innovation—ownership structures, the number of scientists and engineers employed, research and development funding, and the performance of research and development efforts—are analyzed below. Distinctions are identified between foreign ownership; Hong Kong, Macau, and Taiwan ownership; and state-owned and non-state-owned domestic enterprises. SOEs include state-ownership holding enterprises, state-joint-ownership enterprises, and state-sole-funded corporations. Other domestic enterprises are identified as non-SOEs. These include joint-stock enterprises, private enterprises, and others.

From 2002 to 2007 the total industrial output value of all types of enterprises in China has grown. However each ownership type has progressed at a different rate. Not only are non-SOEs clearly progressing at the highest rate, they also boast a 2007 total industrial output value of US$1,577.63 billion. Foreign-invested enterprises produced a total of US$854.97 billion in 2007. In 2007 state-owned enterprises fell to third place with a total output value of US$634.89 billion (see Figure 6).

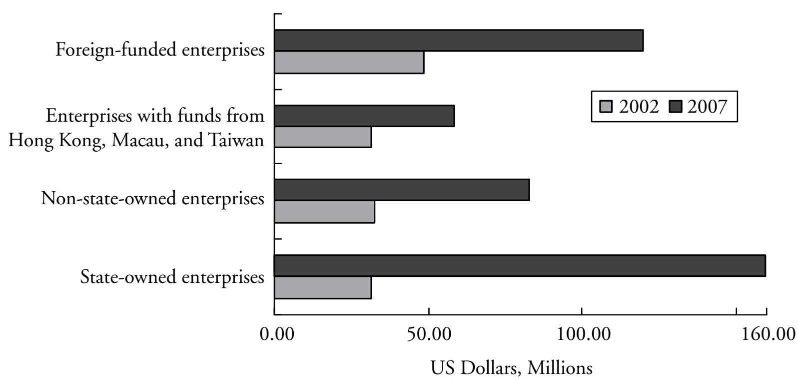
Figure 7 compares the average industrial output value of different ownership structures in 2002 and 2007. In 2007 the average output value of SOEs reached US$1.69 billion, ranking first. Over this five-year period the number of SOEs fell while the individual sizes of such enterprises rose.

Figure 6. Total Industrial Output Value of Medium and Large Chinese Enterprises, 2002–2006



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2007.

Figure 7. Average Industrial Output Value of Medium and Large Chinese Enterprises, 2002 and 2007



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

During the 1990s China transitioned from a planned economy to a market economy. At that time SOEs dominated the entire economy. While the value of SOEs' output as a percentage of the national GDP is currently decreasing, the commercial/political power of SOEs appears to be increasing. SOEs enjoy dominant positions in resource-intensive industries. They are concentrated in the machinery, metallurgy, mining, petrochemical, power, national defense, telecommunications, and transportation industries.

SOEs continue to control many of China's key industries including the banking, electricity, oil, railroad, and telecommunications industries. SOEs control 48 percent of the automobile output, 55 percent of China's electricity supply, and 70 percent of hydroelectric generation equipment (Xinhua.Net 2008a).

At the same time, however, foreign-invested enterprises are rapidly expanding in the manufacture of electrical machinery, information and telecommunications technology, and transportation equipment. Current trends in ownership structure indicate that domestic non-SOEs have increased their share of the competitive market but are still weak when compared to both foreign-invested enterprises and SOEs.

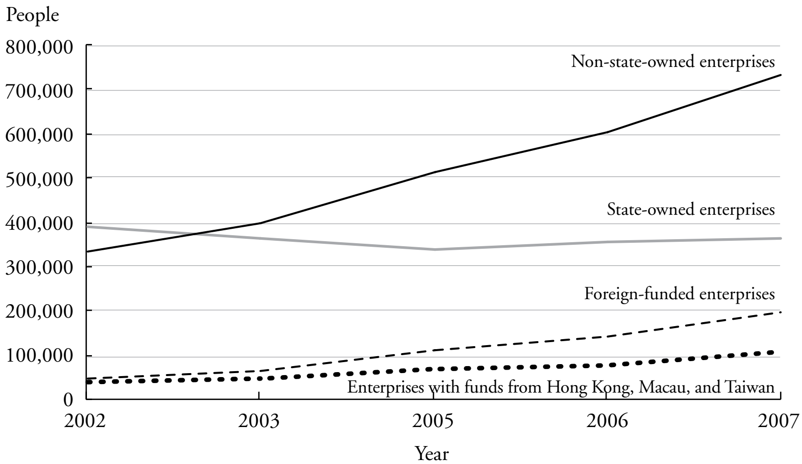
Human Resources in Research and Development

An enterprise's scientists and engineers are that enterprise's main inventors—the individuals who actually drive significant innovation. To keep such employees, enterprises must both pay them well and provide them with high-quality research and development infrastructures. Whether or not an enterprise is innovative largely depends on the number and the quality of the inventors employed.

Whether an enterprise is innovative depends on the inventors employed

In China usually only large SOEs have historically been able to maintain a large number of scientists and engineers as employees. However Figure 8 indicates a clear trend: between 2002 and 2007 the absolute number of scientists and engineers working in SOEs declined. The percentage of scientists and engineers working in SOEs, as a percentage of those employed by all of the noted enterprise segments, declined significantly from 48 percent in 2002 to 25.9 percent in 2007. The absolute number of scientists and engineers hired by non-SOEs with ownership from Hong Kong, Macau, Taiwan, and foreign-invested enterprises increased between 2002 and 2007.

Figure 8. Numbers of Scientists and Engineers Employed by Medium and Large Chinese Enterprises, 2002–2007



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

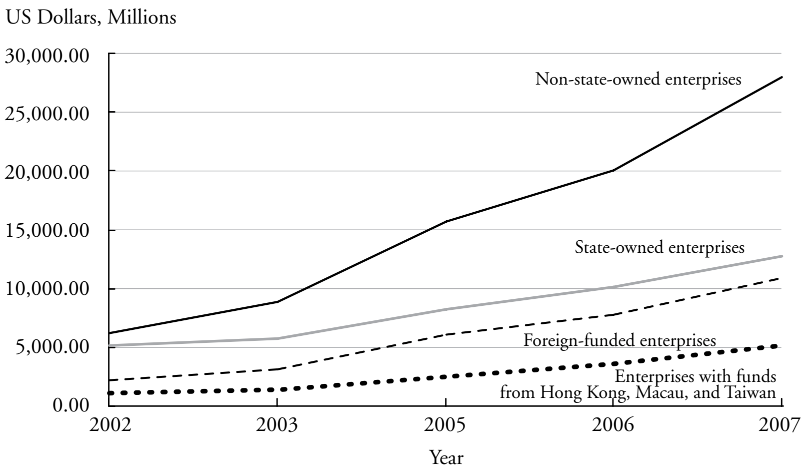
While SOEs have continued to receive strong support from the central government their human resources devoted to research and development appear to have been declining since before 2005. During this same time period non-SOEs and foreign-invested enterprises have steadily increased their research and development human resources.

This trend indicates that a redistribution of innovation resources is beginning to emerge in China and that the earlier pre-2006 innovation policy so favorable for SOEs is no longer significantly detrimental to the innovation efforts of non-SOEs.

Research and Development

Research and development funding is an even more direct indicator of the innovation efforts of various enterprises. With non-SOEs leading the way, all noted enterprise segments have accelerated their research and development funding since 2003 (see Figure 9). By 2007 non-SOEs accounted for 49.4 percent of all noted enterprise segments' research and development funding while SOEs accounted for only 22.6 percent. Foreign-related companies, including those in Hong Kong, Macau and Taiwan, account for about 28 percent. These data indicate that market competition has become the primary driver pushing enterprises to perform research and development.

Figure 9. Amount of Research and Development Funding by Medium and Large Chinese Enterprises, 2002–2007

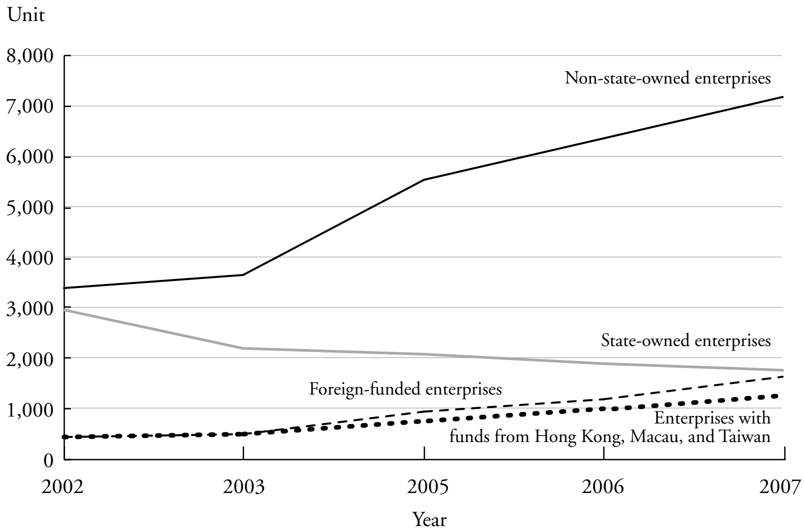


Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

The number of research and development laboratories funded by each enterprise is another important indicator of innovation capability. Figure 10 indicates that non-SOEs are setting up more and more of their own research and development laboratories. By 2007 non-SOEs accounted for 60.5 percent of research and development laboratories while SOEs accounted for only 15 percent, Foreign-related companies, including those in Hong Kong, Macau and Taiwan, account for about 24.5 percent.

Figure 10 indicates that, other than in 2004, since 2002 the number of state-owned scientific research institutions has declined. Figure 10 also shows the increasing growth in ownership of scientific research institutions by all non-SOEs. The growth curves for ownership of scientific research institutions by all non-SOEs are generally similar. It appears that the generally similar growth curves for ownership of scientific research institutions by all non-SOEs result from market competition.

Figure 10. Number of Research Institutions Owned by Medium and Large Chinese Enterprises, 2002–2007

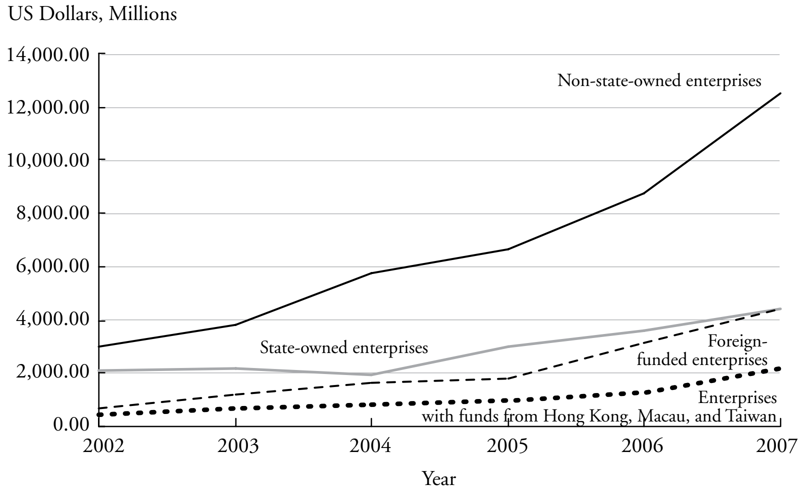


Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

Figure 11 indicates that, while all enterprise segments have received increasing funding for their research and development laboratories, funding for research and development laboratories for private firms, including foreign-invested enterprises, has increased faster than for SOEs.

It is interesting that, although the number of SOE research and development laboratories is declining, funding for SOE research and development laboratories has been growing (see Figure 11). In 2007 funding for research and development laboratories of foreign-invested enterprises had reached the same level as that for SOE research and development laboratories. By the end of 2007 foreign-invested enterprises had set up more than 1,160 research and development laboratories in China (Xinhua.net.com 2008b). Foreign-invested

Figure 11. Funding for Research and Development Laboratories Owned by Medium and Large Chinese Enterprises, 2002–2007



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

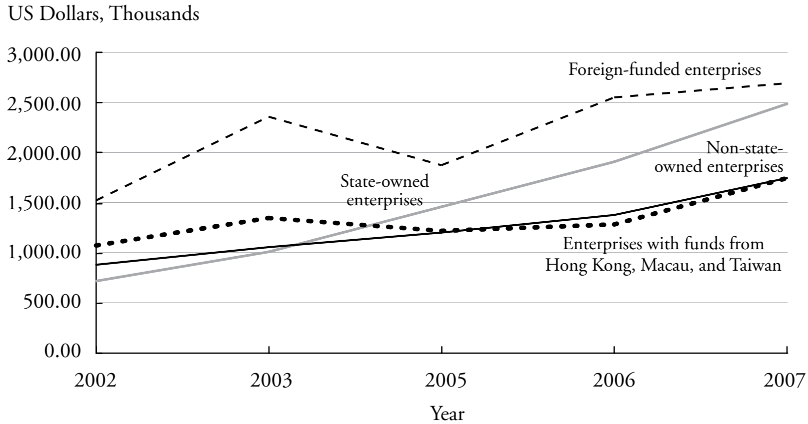
enterprises are funding more and more research and development laboratories in China both to take advantage of China's low labor costs and, presumably more significantly, to increase their capability for innovation to address the needs of both the Chinese domestic market and the global market.

Figure 12 indicates that, on average, foreign-invested enterprises have invested most in their research and development laboratories followed by SOEs, with Hong Kong–, Macao-, and Taiwan-invested enterprises and non-SOEs tied for third place.

Innovation Performance Differs by Ownership of Enterprises

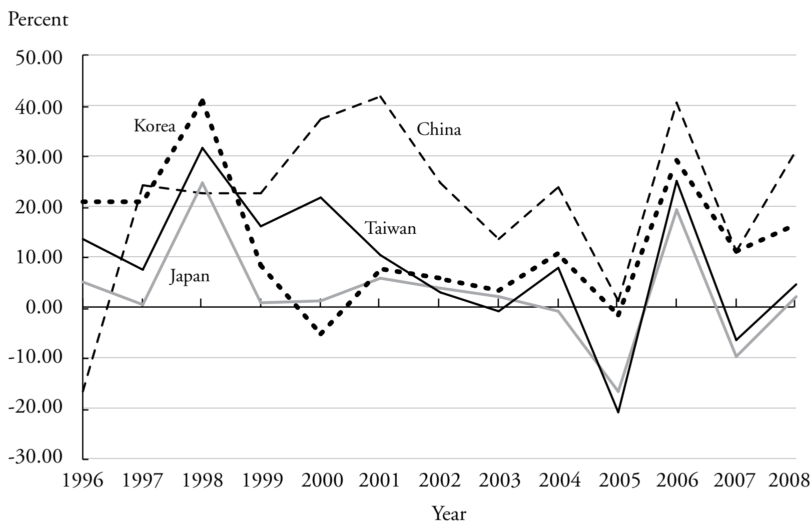
The number of patent applications granted and the value of new-product development are both significant indicators of innovation performance. Measured by the number of US patents granted to enterprises from non-US countries, since 2005 China has shown a quite astonishing increase in the number of US patents granted. China has significantly narrowed the gap with Japan and South Korea in this measurement (see Figure 13). This indicates a rapid increase in Chinese innovation capability following the implementation of the 2006 indigenous innovation strategy.

Figure 12. Expenditures for Research and Development Laboratories by Medium and Large Chinese Enterprises, 2002–2007



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

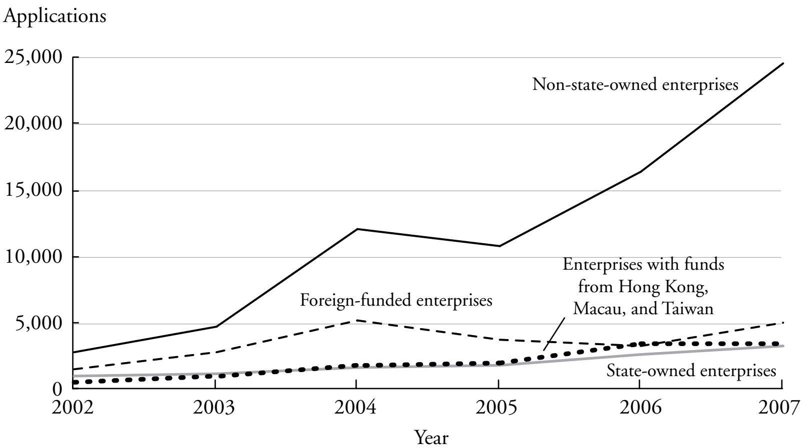
Figure 13. Annual Growth Rate in US Patents Granted to Enterprises from China, Japan, South Korea, and Taiwan, 1996–2008



Source: Online database of the United States Patent and Trademark Office, www.uspto.gov/.

Figure 14 indicates that patent applications by Chinese non-SOEs rose significantly between 2005 and 2007. This validates a belief that the innovation capabilities of non-SOEs have substantially benefited from increases in innovation resources.

Figure 14. Numbers of Patent Applications by Medium and Large Chinese Enterprises, 2002–2007

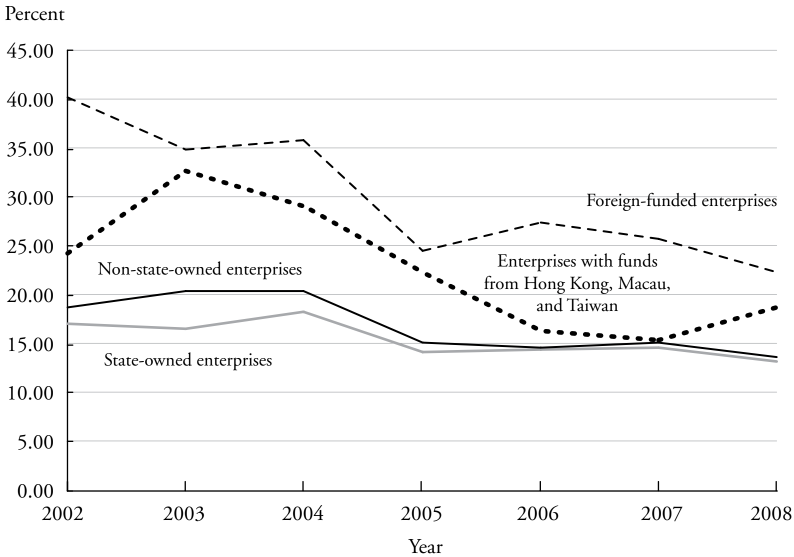


Source: China Statistical Yearbook[s] on Science and Technology, 2003–2008.

Figure 15 indicates that, as measured by an input-output analysis of technological innovation (Gross Value of New Products/Expenditures on New-Product Development), indigenous innovation by Chinese SOEs is less efficient than that of all non-SOEs, although only slightly less efficient than that of Chinese non-SOEs. Increases in resources supporting innovation at foreign-invested enterprises have been significantly more efficient, yielding relatively greater innovation output. It can be seen that private enterprises, though having less funding for innovation, have a higher innovation output, as measured by invention patents and new-product development, than SOEs. Their innovation efficiency is higher than that of SOEs.

Private enterprises, though having less funding for innovation, have a higher innovation output

Figure 15. Gross Values of New Products/Expenditures on New-Product Development by Medium and Large Chinese Enterprises, 2002–2008



Source: China Statistical Yearbook[s] on Science and Technology, 2003–2009.

Discussion and Conclusions

Available data support the conclusion that the 2006 adoption of a Chinese indigenous innovation strategy has resulted in significant changes in the realities of innovation practices within China. Through establishing government-led research consortia and key government-procurement-policy tools, China's government was able to increase its control over the resources available for innovation. In recent years, mega-projects developed by government-led research consortia have become increasingly important. While China's innovation efforts have become even more controlled by the central government, regional governments have also simultaneously played important roles in developing China's innovation systems.

It will be interesting to observe the final results of China's mega-projects and research consortia. Chinese research consortia have been structured in many different forms, some controlled by SOEs, some by universities and government-led research institutes, and some by private enterprises. Research consortia have spread from high-tech to traditional industries. Some enjoy local advantages while others do not.

For the case of the recent development of TD-SCDMA telecommunications standard, both as a beneficiary of the efforts of a large research consortia and as an example of attempting to define a new industrial standard, it is too early to make a final judgment. Recent developments show that, in terms of industrial success, this effort continues to be a high-risk project.

New innovation systems are emerging in China in response to the nation's indigenous innovation strategy. The old national innovation system used the central government, SOEs, and universities and government-led research institutes as the major elements.

The new systems maintain the central government, SOEs, and universities and government-led research institutes as significant elements, but now also are developing innovation from private enterprises, multinational enterprises, and regional governments—with private enterprises significantly becoming the key players.

Private enterprises are now generally the final consumer of most of the research and development done in universities and government-led research institutes and/or supported by government funding. Private enterprises are also now the primary consumers of knowledge spill-over from the various multinational enterprises active in China.

However Chinese efforts in indigenous innovation still face the challenge of building an innovation network with global impact. China's first challenge is determining whether an exceptionally large domestic market is alone adequate to ensure that indigenous innovation will succeed.

In some industries, such as telecommunications efforts involving TD-SCDMA technology, the market driving the adoption of new technology and hardware is global. Given this reality, whether a new Chinese-developed standard succeeds in the market depends on whether multinational enterprises choose to adopt the technology. The international value of TD-SCDMA is not yet obvious. Companies with large multinational sales, such as Nokia, have been conservative concerning the possible use of this technology. With limited multinational adoptions, currently TD-SCDMA telecommunications handsets remain very expensive.

However the current innovation strategy works more effectively in infrastructure-related industries where domestic markets provide the primary demand. In the high-speed-rail sector, for example, the demand is clear. Budgets available for these projects have been massive and government-led consortia have proven successful in addressing the market. The fastest (380km/hour) bullet train in the world has been developed in China (Chen 2010), but the tragic accident that occurred in Wenzhou in July indicated unresolved safety issues and will delay the process of developing more high-speed trains.

Unfortunately, in most internationally competitive major industries, a strategy that relies primarily on the domestic Chinese market, as exceptionally large as that is, is still limited in its potential. The recent project attempting to market large airplanes provides an example of such a difficulty. The C919 aircraft is the product with which Chinese enterprises will be competing with Europe's Airbus and the United States' Boeing in the international market. As noted earlier, this project appears to be progressing much more quickly than predicted and has been reported to already have over one hundred orders for the new plane (Caijing.com.cn 2010). However these orders are all from domestic Chinese SOEs. Though the domestic Chinese aircraft market is the largest in the world, will the domestic market alone provide the critical mass necessary for final success?

In internationally competitive industries, a strategy relying primarily on the Chinese market is still limited

Another challenge to China's developing indigenous innovation strategy involves policy conflicts with western countries. Some western countries argue that current Chinese policy is in conflict with commonly used World Trade Organization (WTO) agreements—especially China's public-procurement policies requiring supplier companies to have a Chinese brand, use Chinese intellectual property, and have at least 51 percent Chinese ownership (USITC 2010). However since China is not yet a signatory to the WTO Agreement on Government Procurement, current Chinese policy on public procurement is legally defensible.

China has also been criticized for using access to its exceptionally large domestic market to leverage foreign-invested enterprises to transfer key technology for use in the high-speed-rail sector (Anderlini and Dickie 2010).

China's policies for establishing standards also worry such organizations as the United States International Trade Commission which has said that in China there is "a clear trend to promote indigenous technology which is developed outside the international standards development system" (USITC 2009). However China's establishment of the TD-SCDMA 3G telecommunications standard followed the pattern used by European countries in establishing the earlier "second generation" (2G) telecommunications standard.

China's central government has used the leverage of the nation's exceptionally large domestic market and a dynamic moment in China's economic history to mobilize both domestic and global resources in support of its indigenous innovation strategy.

In conclusion, China's current indigenous innovation strategy is both constructive and efficient for an economy with clear targets for industrial innovation working to catch-up to international standards. For China to succeed as an innovative country it needs to provide more opportunity for market competition to incubate and generate radical innovations.

China also needs more open innovation policies than those used in the past. A domestic market that is completely inward-facing will not provide domestic enterprises the space needed to become globally innovative companies. Chinese enterprises cannot succeed if they close themselves off from global technologies. Only open innovation policies will provide Chinese enterprises with the opportunity to succeed in the competition for the next wave of international technological innovation and establish China as a truly innovative nation.

Endnotes

1. According to the Ministry of Information, in the first quarter of 2010 users of TD reached 7.7 million. See http://it.sohu.com/20100524/n272314191.shtml.
2. China to Tilt Governmental Procurement to Domestic Hi-Tech Products, http://www.gov.cn/english/2006-02/27/content_211767.htm.
3. See the website of the Ministry of Science and Technology of the People's Republic of China, http://www.most.gov.cn/yw/201009/t20100928_82413.htm.
4. "Huawei Will Not Innovate in a Narrow Indigenous Sense," *21st Economic Report Daily*, May 12, 2009.

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About this Issue

National innovation policies currently attract intense interest throughout the international community, particularly so in the aftermath of the global financial crisis. China is among those countries now relying heavily on government resources to drive innovation—a policy that directly challenges the prevalent theory that government powers have limited effects on a nation's innovation systems. Indeed, China's new indigenous innovation strategy has transformed the country's innovation systems. China's current indigenous innovation strategy is both constructive and efficient for an economy with clear targets for industrial innovation and working to catch up to international standards. For China to succeed as an innovative country it needs to provide more opportunity for market competition to incubate and generate radical innovations.

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