STATE OF INNOVATION

THE U.S. GOVERNMENT'S ROLE IN TECHNOLOGY DEVELOPMENT

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CHAPTER 11

China's (Not So Hidden) Developmental State

Becoming a Leading Nanotechnology Innovator in the Twenty-First Century

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The Push for High-Tech Global Leadership

One way to gain perspective on U.S. government innovation policy is through comparing it with the efforts of other nations. While some nations were strongly influenced by Washington's antigovernment ideology and abandoned any active pursuit of industrial policy, China has done the opposite. Its theoreticians studied U.S. innovation policies carefully and have sought to imitate them. One of the clearest instances of this occurs in the field of nanotechnology. The U.S. government launched a major research and development (R&D) initiative in this area in 1999. China created its own national steering committee on nanotechnology in 2001, and by 2006 nanotechnology was one of the major priorities in basic science in the *Medium- to Long-Term Plan for the Development of Science and Technology* (MLP)—the guiding document for China's strategy of leapfrog development.

China is hardly alone in prioritizing nanotechnology: Germany, Japan, and some forty other countries are betting that nanotechnology, among other high-tech areas, will provide the key to a $2.6 trillion market by 2014—sufficient to confer global economic leadership on the country that attains first-mover advantage through innovation (Holman et al. 2007, iii). An estimated $11.8 billion was invested globally in nanotechnology R&D and commercialization in 2006—$5.8 billion from governments, $5.3 billion from corporations, and $700 million from venture capital (Holman et al. 2007, 11–12). Private investment slightly outstripped public investment for the first time in that year. Governments worldwide have clearly been drivers of nanotechnology during its early stages, and private venture capital remains limited.

In terms of government spending, the United States remains the world leader, with $1.53 billion allocated for 2009, roughly a quarter of the combined amount spent by governments globally on nanotechnology. U.S. government spending is coordinated through the National Nanotechnology Initiative (NNI), "a multi-agency U.S. government program aimed at accelerating the discovery, development, and deployment of nanometer-scale science, engineering, and technology" (US NNI 2008e). Initiated during the last year of the Clinton administration, the NNI has invested some $7.2 billion since it began funding programs and projects in 2001 (AZoNano 2008). Today it encompasses twenty-six federal agencies with nanotechnology-related programs.

The U.S. efforts in this area are explicitly linked to the goal of competitiveness: to make the United States a world leader in this emerging technology. The NNI identifies four overarching goals on its website (US NNI 2008b):

- Advance a world-class nanotechnology R&D program
- Foster the transfer of new technologies into products for commercial and public benefit
- Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology
- Support responsible development of nanotechnology

In its early years, the NNI largely focused on funding basic R&D, but there has been a strong effort to support commercialization through three separate channels that are evident in other technology initiatives (Block and Keller, Chapter 8). First, strong incentives exist to encourage funded researchers at universities and federal labs to create new firms to exploit their technological discoveries. Second, a portion of nanotechnology dollars go to support these start-up firms through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer programs. Between 2004 and 2007, federal government SBIR/STTR programs provided $294 million in support of nanotechnology-related projects, 22 percent coming from the NSF (US NNI 2009, 12).[1] Third, there is a strong emphasis on getting industry participants to collaborate with university and federal lab technologists. The program has funded more than sixty multidisciplinary research and education centers across the United States, primarily at universities but also at several of the national laboratories and some government agency facilities (US NNI 2008c) that are supposed to draw in industry participants.[2] These facilities built with nanotechnology dollars have aggressively marketed their services to industry so that firms can be spared the prohibitive costs of building their own laboratories. Yet notwithstanding the success of these programs, U.S. federal government support for nanotechnology remains heavily weighted toward the research end of the spectrum. A recent report prepared for the U.S. Department of Commerce Office of Technology Assessment, entitled *Barriers to Nanotechnology Commercialization,* identified a host of such barriers, concluding that "the most significant barriers to growth generally include funding which favors research over development and commercialization of nano products (McNeil et al. 2007, 10–11).[3]

In comparison with the United States, China, as a society that has recently transitioned from state-owned to privately owned enterprises, lacks the long history of small

technology start-ups and does not yet have much of a private sector venture capital system. As we will see, China has sought to use a division of labor across different levels of government as a way to solve this problem. Whereas the central government provides much of the R&D funding, local and provincial governments have taken on the role of nurturing start-up firms to build new clusters of nano-based industries.

Data Sources

The following analysis is based on an examination of Chinese government publications (in Chinese and English), as well as field interviews conducted during five weeks of research carried out during the summers of 2006 and 2007. To date we have conducted fifty-nine interviews: thirty-eight in China (Beijing, Tianjin, Shanghai, Hangzhou, Suzhou, and Dalian), six in Hong Kong, eight in Taiwan, and seven in the United States. One of the authors (Cong Cao) has done extensive previous research on China's high-tech policy.[4] The breakdown of our interviews, by type of organization, is summarized in Table 11.1:

Table 11.1 Organizational Setting of Interviews

Type of organization	*Number of Interviews*
Governmental	10
Quasi-governmental (semi-private)	3
Government-funded Incubator	5
University, including labs	19
Companies	17
Other	5
Total	59

China's Emphasis on Government Support for Indigenous Innovation

During the past twenty years China has invested heavily in science and technology (S&T), using reforms in the S&T management system, including higher education, to boost the emergence of a national innovation system that could generate indigenous innovation (*zizhu chuangxin* in Chinese) in areas including biology, information technology, and nanotechnology. Beginning with the Third National Conference on Science and Technology in 1995, when the "decision on accelerating scientific and technological progress" was announced (U.S. 1996), "indigenous innovation" has been heralded as a major source of China's future economic development.[5] Science, technology, and education were identified as the tools that will create national prosperity. In October 2000, Chinese Communist Party secretary and Chinese president Jiang Zemin pointed out in his report in the fifth plenary session of the fifteenth party Central Committee: "We should concentrate our efforts to make breakthroughs on such fields as genome science, information science, nano-science, life science and geosciences" (NIBC 2006, 14). By the time the eleventh five-year plan (2006–2010) was unveiled in 2005, innovation had become the centerpiece of China's economic strategy, and the goal was to harness China's human capital to promote indigenous innovation through S&T in order to address the country's social, environmental, global competitive, and national security challenges.

The Chinese strategy can be termed "technological leapfrogging"—taking an industrialization shortcut. The term was coined in 1985 by Luc Soete with specific reference to the international diffusion of technology and the industrial development of economic growth associated with the microelectronics industry. Soete (1985) highlights the significant advantages that can be felt by "late industrializers" in terms of catching up to global technological leaders, citing Japan as the most apt example (at the time). More recently, it has been linked to countries such as China, which has explicitly jettisoned the traditional notion of sequential or "catch-up" industrialization typically advocated for developing nations dating back half a century or more (Rostow 1971).

China, in particular, is racing toward high-tech development, while continuing to exploit the advantage of paying comparatively low wages in labor-intensive industries (Friedman 2006). What makes China unique, however, is its attempt to build a single development strategy based on three national advantages: its low-cost advantage in export-oriented industrialization; its large domestic market for advanced manufactures that will become more profitable as China substitutes homegrown products for those it now imports, via import substitution industrialization; and its burgeoning talent pool of scientists and engineers associated with the R&D process in high-tech development, which happens to have cost advantage over developed countries.

Two powerful forces, globalization and the rapid advance of information technologies, have made China's distinctive approach to technological leapfrogging possible. These forces have compressed both space and time, reducing the impact of distance between people, products, and information to the point where China is able to upgrade and strengthen many areas of its economy simultaneously: labor-intensive exports (e.g., nondurable consumer goods), increased domestic manufacture and consumption of high-tech products like cars and electronics; infrastructure development (e.g., highways, ports, logistics, and communications), and government promotion of knowledge-based industries (e.g., biotechnology and nanotechnology).

The choice of this development strategy—to leap ahead in so many areas at once—can only be explained by China's expansive vision of its role as an emerging global power and its domestic politics oriented toward rapid economic growth and so-called market socialism. Whether China can successfully sustain this strategy is an open question, but it will require a complex and evolving set of policies and institutions to concurrently manage everything from exchange rates and industrial incentives to education, migration, labor market, and S&T policies. Nanotechnology development policy in China illustrates both the potential and the difficulties of this leapfrogging strategy, which ultimately seeks to help its economy bypass the traditional step-by-step movement up the value chain.

Some China watchers say technological leapfrogging—driven by initiatives that originate in the central government—is doomed to fail. Efforts to create an "innovative society" via leapfrogging are seen as hampered by a lack of private sector resources in China, as well as by bureaucratic rivalries among key state agencies (Suttmeier, Cao, and Simon 2006b). Innovation requires market-driven incentives, while China's investment- and export-driven growth is said to have been at the expense of consumption, and hence a drag on the economy (Lardy 2006). Furthermore, as a strategy for growth, "indigenous innovation" is viewed as suffering from "techno-nationalism," which is largely at odds with the foreign direct investment–oriented development model China has thus far used effectively to bring in new technologies (Serger and Breidne 2007).

We question the dismissal of China's innovation potential on the grounds that it is based on an exclusively Beijing-led model of development. We see in the Chinese model an emphasis on more modular, loosely coupled approach to innovation in terms of John Hagel III and John Seely Brown's perspective of creation nets, open innovation, and process networks (Brown and Hagel 2005; Hagel and Brown 2006). Such approaches favor open over closed systems, recognizing that a balance needs to be struck between open "pull" and closed "push." Similarly, Lynn and Salzman (2007a, b) argue that real innovation shifts are occurring in places like China, but to understand them we need to look at the role of cumulative and incremental innovations, the dynamics of collaborative advantage, and the role of local technology entrepreneurs.

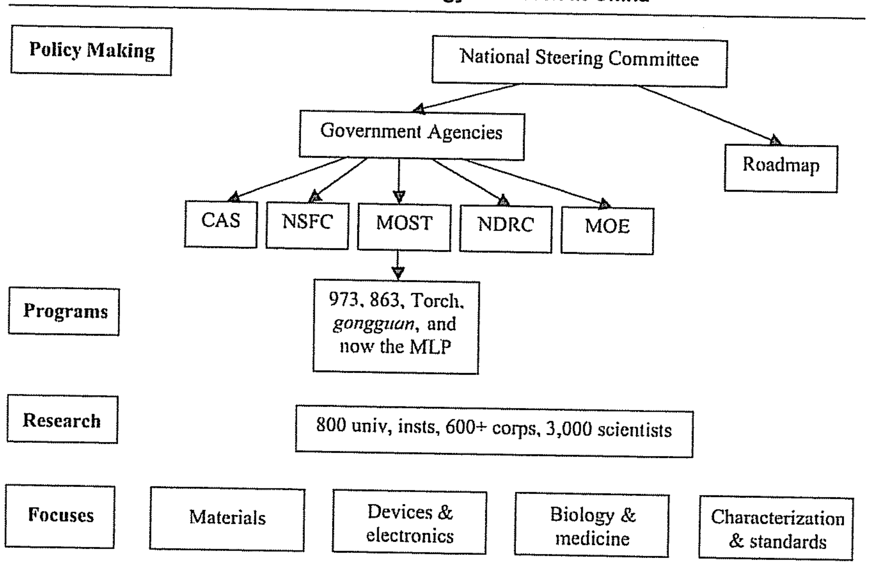
China's Developmental State: Science and Technology Policy

Technological leapfrogging requires state investment in areas where business firms are unable or unwilling to invest (e.g., nanotechnology) that will take years to become commercially viable. Let us start with a brief description of China's science and technology policymaking framework to better understand how nanotechnology has evolved into one of the "leapfrogging" priorities. The National People's Congress (NPC), China's highest organ of the state power and legislature, through its Standing Committee and the Committee on Science, Technology, Education, and Health, has the authority to enact and amend S&T related laws, which are typically drafted by government agencies. The NPC also monitors the implementation of such laws and approves state budget on S&T. The various ministries in China's cabinet, such as the Ministry of Science and Technology (MOST), Education (MOE), Agriculture (MOA), Health (MOH), Industry and Information Technology (MIIT), Environmental Protection (MOEP), the National Development and Reform Commission (NDRC), the now-defunct Commission of Science, Technology, and Industry for National Defense (COSTIND), then allocate resources to programs related to their respective ministerial missions.

The Chinese Academy of Sciences (CAS), an entity with multiple functions in research, high-tech industrialization, technology transfer, and training, plays a significant role in S&T policymaking through its honorific members. So also does the Chinese Academy of Engineering (CAE), an advisory institution providing services for decision-making of the nation's key issues in engineering and technological sciences (Cao 2004). The national Natural Science Foundation of China (NSFC) mainly supports basic research and mission-oriented research projects through a competitive peer review process. Finally, the Ministry of Finance (MOF) has become increasingly important in scrutinizing budgets put forward by ministries and monitoring the usage of the funds. During the policymaking process, members of the Chinese People's Political Consultative Conference (CPPCC), an advisory body, also voice their opinions; this body includes many who are not members of the Chinese Communist Party (CCP). So do leading scientists. For example, in May 2000, a group of experts jointly proposed to the CCP Central Committee and the State Council that "our country should accelerate the industrialization of the nanotechnology and occupy this world-wide frontier area as soon as possible," which was quickly taken up as a priority research area by members of the CCP Central Committee (NIBC 2006).

Pressure for developing a national nanotechnology policy began in these science-based agencies. Initiated in 1982, *gongguan* is a national S&T program administered by the State Science and Technology Commission and its successor, MOST, to tackle critical and generic technologies pertaining to industrial technology and social development. MOST, the State Planning Commission (the predecessor of NDRC), MOE, NSFC, and CAS jointly analyzed the strength, weakness, opportunities, and threats in the development of nanotechnology in China (Figure 11.1). The outcome of the exercise was to establish a national steering committee on nanotechnology in 2001 that coordinates the efforts in nanotech research and industrialization and determines the priority areas for support. The committee formulated the Outline for the National Nanoscience and Technology Development (2001–2010) as a road map for the future of nanotechnology in China. Under the guidance and coordination of

Figure 11.1 The Framework of Nanotechnology Research in China



the national steering committee, chaired by the minister of science and technology (although its chief scientist, Bai Chunli, is from CAS), various nanotechnology-related programs have been supported and implemented at MOST, MOE, CAS, and NSFC; in the meantime, NDRC has provided funds for infrastructure building and research at private companies.

Ultimately, the CCP has final say in S&T policy formulation, as it does in virtually all matters in China. Although the CCP Central Committee does not set S&T policy directly, it does maintain a significant level of influence through the state "leading group" mechanism. A Leading Group usually is set up within the State Council to tackle issues involved with large-scale planning involving more than one government agency to mobilize resources and coordinate efforts. Its chairperson is likely to be a vice premier or higher-level figure who also belongs to the CCP Central Committee Politburo or its Standing Committee—China's de facto governing body. Given the importance attached to "strengthening the nation through science, technology, and education" (*kejiao xingguo*), China's S&T policy has became a national development strategy since the mid-1990s, and the State Leading Group for Science, Technology, and Education has been led by the premier. A vice premier or a state councilor runs the day-to-day operations of the Leading Group, which is also composed of the chiefs of the leading science, education, and economic agencies from MOST, NDRC, MOE, MOA, MOH, MIIT, MOEP, COSTIND, and MOF; the presidents of CAS and CAE; and a deputy secretary-general from the State Council. Many of the bureaucrats working at this level are scientists or engineers by training.

The State Leading Group for Science, Technology, and Education is responsible for studying and reviewing the nation's strategy and key policies, discussing and reviewing major tasks and programs related to these three areas, and coordinating important issues related to science education involving agencies under the State Council and regions. The Leading Group appears to be highly influential in setting the nation's science, technology, and education policy. It meets several times a year, usually prior to major national policy announcements or conferences, to discuss critical issues the nation faces in science and education, and to approve important initiatives and programs. The Leading Group also has invited high-ranking scientists to update its members and the State Council on "hot" science, technology, and education related topics, including nanotechnology.

The Leading Group led the drafting of the *Medium- to Long-Term Plan for the Development of Science and Technology* (MLP), the document that calls for China to become an "innovation-oriented society" by 2020 and a world leader in science and technology by 2050. Soon after Wen Jiabao assumed the premiership at the tenth National People's Congress in March 2003, he convened a Leading Group meeting on May 30 to accelerate the drafting of the MLP. Premier Wen also chaired the Leading Group of the MLP and presided over a series of meetings to review the issues in 2004 and 2005. The CCP Central Committee Politburo approved the MLP in late June 2005. In February 2006, the State Council formally issued the MLP, presumably after intensive negotiations between governmental agencies, especially on large-scale science and engineering programs, each of which may require some billion RMB. In

May 2006, Premier Wen convened another Leading Group meeting to discuss how to implement the MLP, after which the State Council issued a series of detailed measures to be carried out by various government agencies.

A central theme of the MLP is that China can afford to invest previously unimagined sums of money in developing science and technology that might produce long-range breakthroughs that could significantly change the scientific landscape and bring about major economic benefit. However, given its limited financial and human resources, it is impossible for China to launch an effort on all fronts; instead, the MLP concluded China should "do what it needs and attempt nothing where it does not" (*you suo wei, you suo bu wei*).[6] China arguably has little choice but to be selective in supporting research endeavors that will concentrate and best utilize scarce resources. The challenge is how to make the right choices that not only embrace a globally competitive strategy of S&T development but also leverage China's existing advantages to realize its potential.

While MOST has the mandate to manage China's S&T initiatives, it is not the only government ministry that plays a significant role in making and implementing China's S&T policy. According to some estimates, MOST controls only about 15 percent of R&D expenditures appropriated by the Chinese government, which means other government agencies are as important as—if not more important than—MOST in planning, budgeting, and organizing S&T and R&D activities.

The strategy of limiting the resources funneled through MOST might well be a way to manage the risks of a highly centralized strategy. If the Chinese government chooses to prioritize the wrong area, the choice would be highly detrimental. For example, Japan made that mistake when the government over-invested in the fifth generation computer program in the 1980s. In other words, if the areas most critical to the basic scientific breakthrough are not the four—protein science, quantum research, nanotechnology, and development and reproductive biology—chosen for the bulk of government funding, not only would China be wasting enormous amounts of resources—both financial and human—and missing a new scientific revolution, the nation would also be trapped at its current level of S&T development for a prolonged period.

In fact, some Chinese scientists—especially those working overseas, who presumably had a better understanding of how science is "supposed to work"—were critical of MOST's approach of picking champions. Unhappy with the way that MOST organized the State High-Tech Research and Development Program (also known as the 863 Program) [7] and the State Key Basic Research and Development Program (also known as the 973 Program), whose achievements were viewed by some as incommensurate with the amount of investment, skeptical scientists proposed limiting MOST's power or even dissolving MOST and replacing it with an Office of Science and Technology under the premier that would be responsible for formulating China's S&T policy only.[8] They also campaigned to divert MOST's funding power to mission-oriented government agencies and to increase funding to NSFC, which has been doing relatively well in administering resources for basic research in China. As it turns out, the opinions of overseas scientists and engineers were not taken seriously in the final deliberation (Cao, Suttmeier, and Simon 2006).[9]

Nevertheless, the fact that MOST controls only about 15 percent of R&D funds means that it has to persuade other agencies to endorse its priorities. The ongoing conversation among officials at different agencies provides a kind of check on the risks that MOST might be wasting its resources on a technological dead end.

China's Approach: A Hybrid Model

As a state-centered economy, China is trying to drive nanotechnology development from the top through large government investments. As early as 2001, addressing an international forum on nanomaterials, President Jiang Zemin stated explicitly that "the development of nanotechnology and new materials should be regarded as an important task of the development and innovation in S&T. The development and application of nanomaterials and nanotechnology is of strategic significance to the development of high technology and national economy in China" (NIBC 2006).

However, it is a mistake to see the Chinese model as exclusively top-down. China's approach is a hybrid model blending different government agencies, market forces (Xu 2006), and input from large and growing scientific and professional communities. In nanotechnology, this includes the physicists and chemists who have long worked in such areas as carbon nanotubes and nanopowders, the applied scientists and engineers who are transforming nanomaterials into commercial products, and an emerging group of entrepreneurs and venture capitalists who are concerned about bringing new nano-enabled products to the market.[10]

To be sure, each group has its own agenda. But the complex ties among these different communities of scientists, engineers, and businesspeople provide critical feedback that guides government policymakers. Moreover, the pressure for coordination among different levels of government (central, provincial, and local) and different government agencies ensures that promising technological directions are validated by multiple actors. These governmental actors have different agendas and incentive structures, and as a result nanotechnology projects are subject to conflicting and sometimes contradictory performance criteria. There is a division of labor in what and how they fund projects (e.g., people, equipment, cheap land, tax reductions). They also tend to have very different time horizons and attitudes toward financial risk. As one moves from central to provincial to local levels of government funding, the time horizon for return on investment becomes shorter, and there is a tendency to move from intangible (basic research) to tangible (commercial products) results. At the local level especially, government officials expect a quick turnaround in terms of technological development and market applications (Cheng 2007).

While the biggest individual grants come from MOST, NSFC provides many smaller grants (roughly equivalent to $30,000–$45,000 over three years), which are administered using objective and universal criteria. CAS also supports nanotechnology initiatives, but it has a more diversified funding philosophy than MOST. So even within the central government's support for R&D in China, there is a mixture of strategies that combines MOST's directed approach with CAS's bottom-up efforts.[11] Provincial governments also play a significant role, both in provinces containing the major cities (such as Beijing and Shanghai) and also in provinces such as Zhejiang, which neighbors Shanghai, that hope to promote their regional universities as major players by setting up collaborative university science centers. (Zhejiang, for example, has partnered with UCLA to set up the Zhejiang-California International Nanosystems Institute, although with mixed results.) Finally, local governments also play a key role, particularly in major cities (e.g., the Shanghai Nanotechnology Promotion Center and the Suzhou Industrial Park). Both provincial and local governments can also partner with foreign investors, as with the China-Singapore Suzhou Industrial Park Development Corporation.

The areas chosen for the largest public investments in technology and engineering, alongside basic science, mentioned above, are those that address the most pressing challenges facing China in agriculture, the environment, population, health, and national defense. Within nanotechnology, China plans to focus on those nanomaterials and nanodevices that promise the most immediate payoff in addressing such immediate problems as air and water purification, materials with great tensile strength that can be used in a variety of industrial applications, as well as targeted drug delivery. China is already a world leader in the production of carbon nanotubes, for example (Fan 2007). According to Liu Zhongfan, professor of physical chemistry at Peking University, "China is far better now than it was ten years ago—more people are working here and more [and better] instrumentation is appearing in China ... policymakers are beginning to understand that nanodevices are actually the most important part of nanotechnology, not synthesis or incorporation" (Liu 2006).

The support of China's political leadership for nanotechnology has been bolstered with a push from leading scientists both inside and outside of China. CAS executive vice president Bai Chunli, a pioneer and champion of nanotechnology research in China, has been an alternate member of the CCP Central Committee, whose lecture to the Politburo and the State Council in 2000 was deemed influential.[12] Yet China did not realize how valuable nanotechnology could be to both science and the economy until much later than other, more technologically advanced countries. When they finally did, the fact that countries such as the United States had formulated national nanotechnology initiatives made it easier for Chinese scientists to make their case to the scientific and political leadership. Xie Sishen, who now heads up the National Center for Nanoscience and Technology in Beijing, explained to us in an interview that well-respected foreign scientists suggested to Jiang Zemin, Hu Jintao, and others that nanotechnology was worth paying attention to. In meetings with Chinese officials, "governments around the world and delegations from other countries, especially those from advanced countries, frequently mentioned nanotechnology," Xie Sishen said. Their "exchanges and collaborations" on the subject "provided information continuously, which made the Government realize its importance from pure basic research to application to impacts on economy and society" (Xie 2007a).

The connection of Chinese scientists to the international nanotechnology community, and especially to Chinese-origin nanoscientists and engineers overseas, has helped China move toward the frontier of international nanotechnology research. Chinese nanotechnology researchers have thus far achieved some impressive results, especially in nanomaterials. Furthermore, returnees and exchanges with overseas Chinese scholars

have brought new ideas into the laboratory, along with increased participation by Chinese scientists and engineers in international exchanges, widespread international collaborations, and attendance at high-level symposiums (Xie 2007a).

The Chinese effort relies on a variety of different programs. The 973 Program of MOST is dedicated to fundamental research, the 863 Program (also of MOST) funds applied research, while the Industrialization Support Plan (also of MOST) supports projects in the initial stages of industrialization.

CAS positions itself in the national nanotech landscape by conducting cutting-edge research and turning out capable students to join the effort. NSFC awards grants to the best projects and researchers with the potential to achieve a breakthrough at the frontier of international research, as judged by peer review. As of summer 2007, there were some 670 ongoing projects with "nano" in the title, totaling RMB800 million (roughly $115 million), accounting for 8 percent of the NSFC total budget (Li 2007). Most of these were relatively small grants (RMB300,000, approximately $43,000) for three years of project funding, in such areas as nanomechanics, novel nanostructures, quantum dots, carbon nanotubes, and novel cancer and gene therapies.

For actual industrialization projects, usually the central and local Commission of Development and Reform provides funding. However, usually the commission only provides 15 percent of the total funding needed to set up the company—85 percent has to be raised by the potential company before it has even been formed. Sometimes these funds are provided by provincial or local levels of government. But this division is not rigorously observed; leading nanotechnology scientists and institutions are likely to receive funding from many available sources, which then outsource or subcontract the projects.

In the first two years of the MLP implementation, twenty-two institutions have been selected to lead twenty-nine projects (Table 11.2). Of those, twelve are CAS institutes, including the Chinese University of Science and Technology and the National Center for Nano Science and Technology (NCNST), which are also CAS affiliates; the rest are key (*zhongdian*) universities, with the CAS Institute of Chemistry, Beijing University, the CAS Institute of Physics, NCNST, and Tsinghua University having more than one project. Beijing, Shanghai, Jiangsu, and Anhui stand out as the leading centers of nanotechnology, and well-known nanotech scientists, such as Jiang Lei at the CAS Institute of Chemistry, Peng Lianmao and Liu Zhongfan at Beijing University, Li Yadong at Tsinghua University, Yang Hui at the CAS Suzhou Institute of Nano-Tech and Nano-Bionics, among others, are among the chief scientists leading the efforts. The projects are in the categories of nanomaterials, devices and electronics, biology and medicine, and characterization and structure.

While it remains to be seen whether the projects selected will contribute to China's ability to leapfrog in nanotechnology, it is not clear that the resource allocation is sufficient to accomplish the program's ambitious goals. The first two-year fund of RMB262 million ($38 million) has been allocated for the twenty-nine projects, which presumably are composed of researchers from more than one institution. Even when one adjusts for China's different costs structure, the funding intensity for each project—less than RMB5 million per year on average ($721,000)—is not generous. Also of concern is how scientists working on different projects collaborate with each other to generate

Table 11.2 Nanotechnology Projects under the MLP (2006–2007)

Leading Institution	*Location*	*Number of projects*	*Funding (RMB million)*
Dongnan University	Jiangsu	1	4.9
Chinese University of Science and Technology	Anhui	1	4.8
CAS Shanghai Institute of Applied Physics	Shanghai	1	11.2
CAS Shanghai Institute of Microsystems and Information Technology	Shanghai	1	14.0
CAS Institute of Chemistry	Beijing	3	35.5
CAS Institute of Semiconductor	Beijing	1	4.6
CAS Hefei Institute of Physical Science	Anhui	1	13.6
CAS Institute of Physics	Beijing	2	13.3
CAS Technical Institute of Physics and Chemistry	Beijing	1	5.0
CAS Institute of Theoretical Physics	Beijing	1	9.0
CAS Institute of Metal Research	Liaoning	1	5.8
Sun Yat-sen University	Guangdong	1	11.7
Beijing University	Beijing	3	31.3
Beijing University of Aeronautics and Astronautics	Beijing	1	9.3
Nanjing University	Jiangsu	1	8.7
Nankai University	Tianjin	1	4.8
Sichuan University	Sichuan	1	10.8
National Center for Nano Science and Technology	Beijing	2	16.2
Fudan University	Shanghai	1	11.2
Wuhan University	Hubei	1	5.5
Tsinghua University	Beijing	2	17.3
CAS Suzhou Institute of Nano-Tech and Nano-Bionics	Jiangsu	1	13.6
Total		29	261.8

synergy and what benchmarks will be used to evaluate the first two-year performance and determine continuous funding. It would be useful to know how these projects have been selected and whether scientists were on equal footing in the process. Although under the MLP, the projects are supposed to be oriented to basic research, some deal with applied nanotechnology. There are further questions about how they are related to other MOST-administered programs related to nanotechnology, especially the 863 Program and the Torch Program, which are focused on high-tech industrialization, and presumably led in some cases by the same chief scientists.[13]

Private Capital: A Limited Resource

In our focus on the developmental state in China, we have not directly addressed the role of private capital, in part because it has not been a large one. Because the bulk of nanotechnology's global commercial promise lies in the future, commercialization prospects remain limited. Nonetheless, we can offer some preliminary thoughts on the role of market investments, based on our research to date. These include centralized investments by large vertically integrated multinationals, various forms of network-based international collaborations, and small-scale start-ups that focus on commercial products.

Multinationals. A great deal of attention has been given to the more than 1,000 R&D centers that have been established by foreign-invested enterprises, including some multinationals, in China during the past decade. In many cases, these R&D centers seem much closer to the *D* of development (e.g., localization and debugging of products) than the *R* of research. However, the Microsoft Research Asia, formerly Microsoft Research China, in Beijing has been touted as "the Bell Labs of China" for its pioneering research activities (Buderi and Huang 2006), and IBM, General Electric, Siemens, and other top multinationals are also implementing innovative projects in China. Lynn and Salzman (2007a) make the case that significant innovation is taking place in emerging economies, but often this is in the form of process innovations rather than functional products.

International collaborations. There are many forms of international collaboration, including formal institutional partnerships between universities and corporations; university study abroad programs, particularly postgraduate degrees earned by Chinese in the United States, Japan, and Europe; exploiting ethnic ties, most notably by recruiting overseas Chinese scientists and engineers to return to China; and development of informal personal ties, as when American professors or business leaders mentor their former graduate students after they return to China. Universities are an important component of China's nanotechnology initiative because it is first and foremost a science-based program.[14]

Entrepreneurial initiatives, such as small firm start-up. In business terms, the "valley of death" refers to the transitional period between basic R&D for a new technology (technology creation)—typically supported by public funding and commercialization—and when a marketable product attracts private sector support. In China, the valley is long and deep. State-run firms—which still account for an estimated 43 percent of GDP, despite China's commitment to privatization—tend to be bureaucratic and conservative, shunning potentially risky investments in favor of short-term, more predictable returns.[15] The emerging private sector, including many small and medium enterprises (SMEs), remains small, undercapitalized, and generally risk-averse. This poses a challenge for the Chinese government's heightened emphasis on leapfrogging development through nanotechnology, whose major payback remains ten or more years in the future. The amount of money allocated from Beijing for nanotechnology is not large by international standards (Xie 2007b), although it is difficult to accurately estimate total public spending for nanotechnology in China, given the wide range of funding sources and the difficulty of defining what qualifies as nanotechnology. Consequently estimates vary widely, ranging from as little as $230 million for the five-year period 2000–2004 (Bai 2005, 63), to $160 million in 2005 alone (Bai and Wang 2007, 75), to $250 million in that same year (Holman et al. 2007, 25). Although even the highest figures are still considerably less than the United States is publicly investing (as noted previously, $1.5 billion in 2008), China's government spending on nanotechnology may not be far off when adjusted for differences in labor and infrastructure costs (nanotechwire.com 2005).

Throughout our interviews, the most pervasive theme to emerge was the importance of government funding and support for nanotechnology throughout the value chain, not only for basic research but well into commercialization. Esther Levy, editor of the journal *Advanced Materials*, who has reviewed numerous submissions to her journal by Chinese scientists, saw the question of government funding as key: "The Chinese are very hard working. As long as the government keeps funding them, they will progress. The question is, will the government funding be patient long enough"? (Levy 2006) As one interviewee commented, "There is a saying in China that those who do research on atomic bombs (*yuanzi dan*) don't make as much as those who sell tea eggs (*chaye dan*)" (Xu 2006). He noted that this situation has to change, since economic returns (rather than pure patriotism) will be required if China is to achieve its high-tech aspirations. Another informant—an academician with the Chinese Academy of Engineering and chairman of China's Desalination and Water Reuse Society—explained the challenges of developing seawater filtration that employs nanotechnology, a NSFC-funded project that has yielded promising results in the laboratory:[16]

> However, it is a little hard to estimate the timeframe for industrializing the new process. China Water Tech is currently working on optimizing the process. And speed for it to move to industrialization will depend on government funding and industrial interest. Government funding is usually not at all enough to industrialize a technological process, industrial involvement is crucial. However, larger scale demonstration of this process needs to be done (likely via government funding) before industry would become interested. (Gao 2006)

At the local level, various forms of incubation play a key role. For the Beijing region, the Nanotechnology Industrialization Base of China Entrepreneurship Investment Co. (NIBC)—located 100 kilometers from Beijing in the Tianjin Economic and Technological Development Area—serves this role. NIBC was established by MOST in December 2000, in conjunction with CAS, universities, and private enterprises. Its distinguishing feature is that it is essentially "a government organization run by market forces," reflecting the belief that

> pure state ownership does not work well for technology innovation or management.... What the NIBC does is to take results from universities and institutes, and help scientists to commercialize the results. It takes a systematic approach that goes to the end of the commercialization pipeline.[17]

NIBC is the vehicle for incubating new companies, acquiring existing companies, and preparing initial public offerings. In 2005, the Chinese National Academy of Nanoscience and Engineering (CNANE) was established under the same administration as NIBC with a primary focus on R&D rather than commercialization. It is unclear to us how large a role these institutions actually play; during our visit in 2006, the principal operation we observed was the manufacturing of non-nano pharmaceuticals, as a form of income generation for the facility.

Shanghai has its own incubator in the form of the Shanghai Nanotechnology Promotion Center (SNPC), which is funded largely by government initiative, particularly the Shanghai municipal government as well as the NDRC, although local enterprises have also contributed.[18] It was founded in July 2000, with the center's formal activities starting in 2001. SNPC is subordinate to the Science and Technology Commission, the lead government agency in Shanghai concerned with advancing the city's high-tech profile. The SNPC provides training for scientists and engineers on the specialized instruments used in nanoscale research and has several university-affiliated industrialization bases for the purpose of transferring research on nanomaterials and nanoparticles to the estimated 100–200 SMEs reportedly engaged in nano-related R&D in the Shanghai area. Roughly a third of its twenty-five-person staff members are science and engineering professionals.

The center's main focus is to promote commercialization. This is achieved in various ways: by funding basic application research;[19] through a research platform designed to help with the commercialization process; through the provision of nano materials testing; through the hosting of workshops and international conferences on nanotechnology; and through education (including a certificate program) and outreach to raise public awareness about nanotechnology. As an incubator, the SNPC provides services for start-ups before and as they enter the market—services that include legal advice for establishing a company, a variety of technology-related services, and help with marketing products.[20] The center also loans out lab and office space as well as a testing center that provides the costly equipment required for nanomaterials characterization—equipment that most start-ups could not afford. It currently supports some seventy to eighty companies, of which perhaps half are nano-related, with grants ranging from RMB50,000 for smaller projects to RMB1 million for large ones.

While there is some private industry investment in nanotechnology (local examples include limited investments by Baosteel and Shanghai Electronics), local government funding plays a key role in China. During our visit to the SNPC, we saw a number of examples of such support—private firms housed within the center's complex that receive public funding as well as access to center support and services.

Three examples are illustrative. The Shanghai Sunrise Chemical Company, which employs about eighty people making nanocoatings and nanophoto catalysts, received two-fifths of its initial capitalization of RMB5 million ($721,000) from government sources. The Shanghai NML Nanotechnology Company develops antibacterial and photo catalysts for use in textiles and plastics. Last year they began exporting the final products employing their materials (such as coffee cups that use nanopowders) to the United States and Australia. While the company has not received money from SNPC, it does have access to the center's training and information services. One final example is the Shanghai AJ Nano-Science Development Company, which manufactures atomic and scanning tunneling microscopes, two key instruments used in nanotechnology. AJ Nanoscience's principal funding comes from the Shanghai Aijian Trust Investment Company, a Chinese firm with significant Hong Kong ownership that invests in SMEs.[21] The company gets public support as well: it receives funding from the

Shanghai municipal government for R&D, relies on technology developed initially in the CAS Institute of Applied Physics, and has some projects with the Shanghai branch of CAS.[22] AJ Nanoscience, which was established in 2001, reportedly has 60 percent of the domestic market in its area of instrumentation—although the market is dominated by international players such as the U.S.-based Veeco Instruments.[23]

Shanghai's city government also supports the Climbing Mountain (*Dengshan*) Action Plan, which provides dedicated funding for joint projects that must be led by companies in collaboration with an academic partner. Within the plan, most work is contracted between university researchers and engineers/business partners from companies. The plan specifically earmarks funding for nanotechnology, with projects divided between basic and applied research intended for nanotechnology commercialization (Jia 2006). In Shanghai, as is typical of funding at the local level, the government provides funding for local players and for local collaboration with foreign companies such as Unilever (Li and Wang 2006). At the provincial and local levels, government funding is trying to make up for the weakness of funding from private capital (Li, Shi, and Min 2006).

Conclusion: China's Developmental State

China's dedication to high-tech growth is evident in its policies supporting efforts to leapfrog development through targeted science megaprojects in nanotechnology, development and reproductive biology, protein science, and quantum research. As we have shown, China's approach to nanotechnology is heavily state centered, with public investment originating at all levels of government, and ranging from support for basic research to funding intended to promote commercialization. Given China's relative lack of private business funding for commercialization, government at various levels has sought to pick up the slack, providing funding to get technological breakthroughs into the marketplace.

The Chinese model represents a complex mixture of centralized and decentralized elements. For example, the Chinese Academy of Sciences Knowledge Innovation Program (KIP, which is funded largely through the 973 Program) is typically treated as an example of decentralized influence of the scientific community, but it involves a significant amount of centralized targeting within the academy. The existence of multiple and overlapping funding sources introduces a significant element of decentralization where multiple agencies are reviewing the efforts of key scientists and institutes. Finally, we have seen that local and provincial governments and decentralized incubators play a central role in supporting the commercialization process.

Whether China's efforts to achieve first-mover status in nanotechnology are successful remains to be seen. Whether there will be any large-scale payoff also remains an outstanding issue in the future development of nanotechnology-enabled market applications. But one thing seems to be clear: nanotechnology in China is still largely in the stage of basic research, as is the case with most nanotechnology research outside of China as well. However, China has clearly shown itself to be very committed to adding high-tech initiatives like nanotechnology to its top national priorities, thereby showing the dynamism of its contemporary developmental state.

Notes

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1. In 2004, SBIR and STTR awards totaled $61.4 million; in 2005 the amount was $63.1 million; in 2006, $86.6 million; and in 2007, $82.7 million. While funding in 2007 came from nine agencies (DOD, NSF, DOE, NIH, NASA, NIST, EPA, NIOSH, and USDA), 81 percent came from the first five in this list (U.S. NNI 2008f, 12).

2. The principal vehicle for NSF funding (as of October 2008) has been fifteen nanoscale science and engineering centers (NSECs) on fifteen university campuses, and twenty-two university-based materials research science and engineering centers (MRSECs), four of which are fully dedicated to nanotechnology research, with eighteen having one or more nanotechnology research groups. The DOE has nanoscale science research centers at five national laboratories (Argonne, Lawrence Berkeley, Sandia/Los Alamos, Brookhaven, and Oak Ridge). For a complete listing (and websites) of NNI centers, networks, and facilities, see www.nano.gov/html/centers/nnicenters.html.

3. According to the report, "critical barriers to nanotechnology commercialization include the ten year cycle time from science results in a laboratory to a commercial product ... the gap between researcher and applied scientists; the gap in funding between basic research and applied research; a lack of understanding that for every dollar invested in basic research almost $100 is required for a commercially viable product, and a list of constraints including, time to patent, uncertainty of potential regulations by EPA, OSHA, FDA; and the high risk of new scientific results becoming commercially viable.... It appears that start-up nanotechnology related companies are struggling to realize revenues and most are not at the breakeven point" (McNeil et al. 2007, 10–11).

4. Cong Cao (2004); Cao and Simon (2009); Suttmeier, Cao, and Simon (2006b).

5. While the 1995 conference did not formally use the term "indigenous innovation," it did call for an increased capacity "to create technology indigenously and master key industrial technologies and systems design technologies" (section 4, as reported in U.S. 1996). At the same time it also stated that "while developing scientific and technological capabilities primarily on our indigenous efforts, adequate attention should also be assigned to the acquisition and assimilation of foreign technology. On the basis of equality and mutual benefit, a significantly greater level of international S & T cooperation and exchange through official, non-governmental, bilateral and multilateral channels should be vigorously assumed" (PRC 2003).

6. This theme was taken from the then CCP general secretary Jiang Zemin's report to the fifteenth CCP Congress in 1997, which reads, "We should formulate a long-term plan for the development of science from the needs of long-range development of the country, taking a panoramic view of the situation, emphasizing key points, *doing what we need and attempting nothing where we do not*, strengthening fundamental research, and accelerating the transformation of achievements from high-tech research into industrialization" (emphasis added). This was in turn adapted from the May 1995 decision of the CCP and the State Council to push

forward China's S&T progress, although the wording was slight different: "catching up what we need and attempting nothing where we do not" (*you suo gan, you suo bu gan*).

7. The 863 Program was seen as a key vehicle for improving China's high-tech competitiveness, through the development of six advanced technologies selected as central to promoting economic growth: electronics, supercomputers, telecommunications, avionics, GPS, and nanotechnology (MOST-863 2001; Larson 2004).

8. The 973 Program sought "to strengthen the original innovations and to address the important scientific issues concerning the national economic and social development at a deeper level and in a wider scope, so as to improve China's capabilities of independent innovations and to provide scientific support for the future development of the country" (MOST-973 2004).

9. In recent years, MOST has been criticized for its inaction in handling misconduct in scientific research in China. The appointment of Wan Gang, a non-CCP member, as the minister of science and technology in April 2007, bypassing another non-CCP member high-ranking vice minister, seems to signal the importance of non-CCP members in government and indicate that the government may not be satisfied with MOST leadership, and in turn the progress of Chinese science, in spite of the large sums of money going into it. They may want someone with no previous relations with the ministry to bring in new ways of thinking and management.

10. Nanotubes are a form of carbon with unusual tensile strength that gives it potential for a variety of industrial uses. Nanopowders are extremely fine forms of elements such as iron that are believed to have considerable potential as a catalytic agent in fuel cells.

11. Many CAS members privately report that this is a "top design" (*ding ceng she ji*) approach, originating under the initiative of Lu Yongxiang, who was president of CAS in 1998 (for a discussion of CAS and the Knowledge Innovation Program, see Suttmeier, Cao, and Simon 2006a, b).

12. Bai, executive vice president of CAS with the rank of a full minister, is in line to succeed Lu Yongxiang as president. But Bai, an alternate member of the CCP Central Committee since the fifteenth CCP Congress in 1997, was not promoted to full member in the seventeenth CCP Congress, concluded in 2007, while Lu not only kept his full membership (which is rare as he is over 65, the age limit for being a full member) but also started his third term as CAS president in March 2008.

13. The Torch Program is intended to produce high-tech products involving new materials, biotechnology, electronic information, integrative mechanical-electrical technology, and advanced and energy-saving technology—products that have commercial potential for both Chinese and foreign markets. It involves, among other things, the creation of high-tech industrial development zones.

14. Why should we consider international collaboration as a form of market investment in high-tech development? If we view nanotechnology as a value chain that has distinctive governance structures, then international collaborations may be a form of relational governance, which has different characteristics than hierarchies (vertical firms) and markets (entrepreneurial start-ups). "Captive" and "modular" forms of governance, which complete the fivefold global value chains typology, may also have analogs in nanotechnology (Gereffi et al. 2005).

15. OECD, *Policy Brief: China's Governance in Transition* (September) (www.oecd.org/dataoecd/49/13/35312075.pdf). In 1997 President Jiang Zemin called for privatization (*feigongyou*, or "nonpublic ownership") of state-owned enterprises (SOEs), a plan that was ratified by the ninth National People's Congress the following year.

16. Gao is one of the founders of membrane technology in China. He introduced the term "nanofiltration" to China in 1993.

17. Handout from NIBC, August 3, 2006.

18. Information was obtained during interviews at the SNPC with Li Xiaoli (project manager), Shi Liyi, and Min Guoquan (August 7, 2006), and with Zhu Simon (SNPC Chinese Industry Association for Antimicrobial Materials & Products; Shanghai NML Nanotechnology Co.), Zhang Bo (Shanghai AJ Nano-Science Development Co.), and Fu Lefeng (Shanghai Sunrise Chemical Co.), (August 3, 2007).

19. For example, we were told that SNPC helped fund and manage a project involving the use of atomic force microscope tips to locate DNA molecules that involved CAS and Shanghai Jiao Tong University, which was featured on the cover of *Nano Letters*.

20. The SNPC has three incubators, each associated with a university: one affiliated with Shanghai University, and two with the Hua Dong Science and Technology University (East China University of Science and Technology).

21. Hong Kong Mingli Co. bought more than 40 percent of Shanghai Aijian Trust Co. in 2004, signaling greater openness to foreign investors on the part of Chinese trust companies. See Zhao 2005.

22. We were told that when profits are realized, they are shared with CAS members who created the technology.

23. AJ Nano-Science's instruments typically sell for roughly one-quarter the price of their foreign counterparts. Interview with Zhang Bo, manager of Research and Production Department, Shanghai AJ Nano-Science Development Co., August 3, 2007.