15: Technology and S&T Policy

What will China become during the 21st century? With vast manpower resources, an industrious and relatively well-educated workforce, high saving and investment rate, and reasonably well-crafted economic policies, there is no doubt that China will emerge as the largest economies in the world. Yet size is not the only important measure, nor does it define the limits of Chinese aspirations in assuming a global role in the coming decades. Will China become simply another middle income developing country, albeit one of enormous size? Will China remain in the foreseeable future what it is today: the world's factory, churning out massive quantities of laboriously produced goods? Or will China instead vault into the front ranks of world economies by contributing new products and procedures, innovative standards; and breakthrough ideas? The most important factor deciding this question will be the pace at which China adopts, adapts, and transforms the world's body of science and technology. We have already seen the examples of Japan, Taiwan, and Korea, which in the process of developing economically, have accumulated formidable resources of human skill and technological ingenuity, and have already contributed significantly to the world's supply of knowledge, ideas, and products. In China today, there is a massive pool of talent and ingenuity that has only begun to be tapped. There is no doubt of the global impact when the potential of this under-utilized resource is finally realized. Moreover, if China does *not* become a world technology power, it will not be from lack of effort on the part of the Chinese government. Perhaps no issue more effectively unites policy-makers and businessmen at all levels in China than the need to propel China into a high technology future.

China's technical capabilities today, however, are still quite mixed. Seki Mitsuhiro (1994) suggested twenty years ago that technological capabilities in general can be likened to a pyramid. The broad base of the pyramid consists of basic manufacturing capabilities such as forging, welding, and machining, exemplified by a simple machine shop. The intermediate zone represents complex manufacturing and assembly-line skills, exemplified by an automobile factory. The apex of the pyramid represents science and research capabilities, exemplified by a laboratory or a research institute. China, according to Seki, is unusual in that it emerged from the socialist era with a strong base, and also with surprisingly strong capabilities at the apex. That is, basic industrial skills are widespread, and pockets of excellence in scientific and technological research are near the world frontier. But in the middle, China has been weak. The productivity of mass production, assembly line industries in China is still low, and China very few first-class firms with significant leading edge technologies. As a result of their weaknesses in these intermediate areas, China has been endeavoring to strengthen its industrial technology. China is trying to move its scientific capabilities "down" to the factory floor, while attempting to upgrade its existing factories to a higher level of skill.

One approach to analyzing technology in an economic context is to consider the triad of **technology effort** (reflecting the volume of resources thrown into research and development [R&D] and the policy strategy that guides it); the **human resource base** (which defines the possible capabilities, and reflects the long-run outcome of the technology effort); and the **institutions and incentives** that determine what ideas and technologies actually get applied to the production process (Cliff 1998). Together these make up a **knowledge production function**, analogous to the aggregate production function that describes the entire economy.

Technological Knowledge = f(R&D, human resources, institutions, policy)

The technological knowledge that comes the knowledge production function is then in turn an input into the aggregate production function. Conceptually, this is clear, and the clarity is essential because in practice measuring the effects is quite difficult. Obviously, knowledge is intangible and cannot be directly measured. Various proxies are available: for example, patents or publications in scientific journals. These obviously have value, but must be analyzed carefully to avoid obvious potential pitfalls. From the economic perspective, we are most interested in technological knowledge precisely because it increases the efficiency with which other inputs can be used in the aggregate production function. That is, capital, labor and human capital can be combined at a higher level of overall productivity in the presence of more technological knowledge. This suggests that increased technological knowledge should show up in an increase in total factor productivity. Total factor productivity, in turn, could be measured either at the enterprise level or at the aggregate economy-wide or sectoral level, and tested for responsiveness to the factors that we expect to increase technological knowledge. However, we expect the impact of technological knowledge to be diffuse and apparent only after substantial time lags. Moreover, the effect of technological knowledge will be confounded with other long-term factors such as quality of institutions and appropriateness of incentives. Thus, while we are convinced that technological knowledge can be produced by appropriate investments in research and human resources; and equally convinced that technological knowledge makes an economy more productive, we should be modest about our ability to demonstrate the precise magnitude and nature of these linkages.

This modesty is especially appropriate because many years of research on innovation and technology has consistently found that the impact of science and technology on productivity is extremely gradual. That is, only a very small portion of the economic productivity gains from major innovations are experienced when the "invention" is created; the vast majority of productivity gain comes during the "Beta" phase, in which multiple incremental changes drive down costs and improve efficiency. From the steam engine to the microprocessor, break-through ideas at first produce ingenious products or processes that have only a modest impact on overall productivity, in part precisely because of their novelty. However, successive generations of the same basic technology continuously produce incremental productivity gains for decades. Perhaps the classic example is the diesel engine, produced in the mid-1890s. Today's diesel engines, 120 years later, use the same fundamental technology, but at a level of efficiency that would have been inconceivable in the early decades. This pattern is true of many technological advances (and especially for the thirty or so "general purpose technologies," such as electricity, that have transformed broad swathes of the productive economy). These general considerations frame the following consideration of China's technology effort.

15.1 The Technology Effort

Developing countries face immense technological challenges. Today's modern technologies come almost entirely from the rich countries, and developing countries are quite marginal in the global innovation process. The continuous stream of innovation emerging from the rich countries ensures that most of tomorrow's technologies will also come from developed economies. To be sure, this disproportion could potentially be a source of advantage for late developers. Since there is a substantial technology gap, there is an enormous backlog of modern technologies that developing countries could in principle adopt. Rather than expending resources on risky and uncertain research, developing countries could concentrate on transfer and adaptation of existing technologies. They ought to be able to pick and choose the "best" technologies, combining selected technologies with their inexpensive production factors to build competitive advantage for their companies.

But in fact, developing countries have enormous difficulties exploiting these potential advantages. It takes time and skills to be able to identify the technologies that are available and appropriate. When new technologies are purchased, it can take substantial effort and resources to actually get the technologies working on the factory floor, and productivity and profitability are typically low for a prolonged period as various bugs are worked out. Moreover, companies in developed countries increasingly view their technologies as income sources, and fence off their intellectual property rights (IPR) with patents or secrecy. Developing economies have found it difficult to develop their technological capabilities and almost impossible to catch up with the technology leaders. Indeed, after Japan, only the East Asian economies of Korea, Taiwan, and Singapore stand out as unambiguous technology success stories. One important implication of the growing recognition of difficulty is that developing countries have increasingly welcomed foreign direct investment (FDI). Most developing countries today hope foreign investors will help build capable industries, from which knowledge and technological capabilities will gradually spill over to the rest of the domestic economy. China fits into the general pattern of opening widely to FDI, and this is an important characteristic that clearly differentiates China from the past technology and industrial policies of, for example, Japan and Korea. Those countries restricted incoming FDI while promoting investment in domestic firms. Chinese policy-makers are sometimes tempted to emulate Japanese or Korean technology and industrial policies, but they do so in the context of a very different relationship with multi-national technology companies. The greater openness to FDI is, in a sense, a characteristic of the global environment to which China has little choice but to adapt.

Whatever the global environment in which a country operates, it must invest resources in research and development (R&D) in order to discover and adapt new, more productive technologies. The general pattern of spending on research and development (R&D) by successful developing countries is quite clear. Low and lower-middle income countries spend relatively little on R&D, typically less than 1% of GDP. Since it makes no sense for them to re-invent the wheel, they spend modest sums on the identification and adaptation of foreign science. As economies approach middle-income status, their indigenous technology effort increases: They make more profound adaptations of existing technologies; absorb technologies that are closer to the developed economy frontier; and engage in some limited basic research. Expenditures on R&D begin to rise. For example, both Taiwan and South Korea pushed the R&D/GDP ratio above 1% in the early 1980s, as they reached middle income status and began to engage in much more challenging innovative activity. As economies reach developed country income levels, the R&D/GDP ratio typically increases above 2%. For example, Korea crossed this frontier in 1992, and Taiwan in 1999. A handful of countries—Japan, Sweden, and Finland—had ratios above 3% by the end of the 1990s. They find a technological effort of this magnitude is required to remain at the technological frontier. Ten years ago, in 2003, China was about where on would expect, with a technological effort, in proportional terms, somewhat ahead of comparable economies such as Brazil and India, but still well short of Taiwan or Korea. However, over the past decade, China has stepped up its inputs into the technology process much more rapidly that one would ordinarily have predicted.

15.1.1 The Trajectory of China's Technology Effort

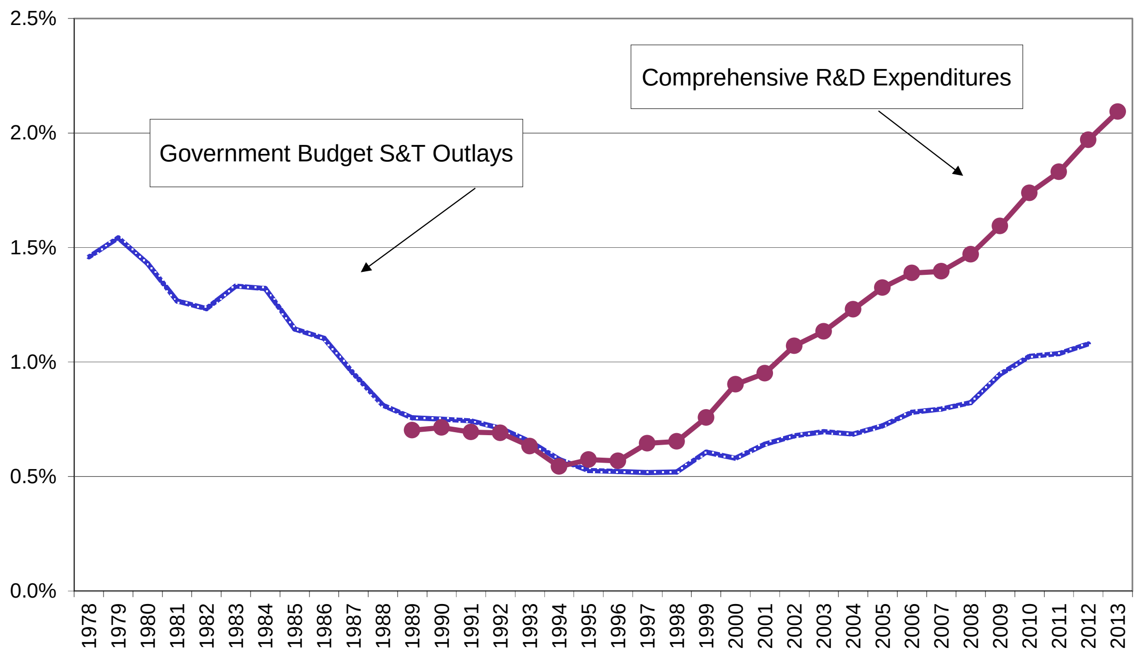
Paradoxically, though, looking backward, the trajectory of China's technology effort does not follow the standard pattern of steadily increasing technology effort at all. From the 1950s through 1978, China, despite being a low income country, pursued a high technology effort strategy. China mobilized available intellectual resources for defense purposes, and created elite research institutions, particularly in the Chinese Academy of

Sciences (CAS). Government outlays for science and technology-related purposes (there are no R&D data before 1989) actually peaked at 1.7% of GDP in 1964, the year China exploded its first atomic bomb, and averaged 1.4% of GDP from the late 1950s through 1978. Despite the apparent anti-intellectualism of the Cultural Revolution, China in fact mobilized substantial intellectual resources for its critical technologies effort. There were successes, especially military: atom and hydrogen bombs and inter-continental missiles. The big effort was completely consistent with the command economy and Big Push strategy described in Chapter 3.

The Soviet Union was China's technology patron during the 1950s. The Soviet Union transferred not only the technologies themselves—having a profound impact on every aspect of Chinese industrial and military technology—but also the key institutions that shape incentives to adopt technology. The organizational structure of the entire national system of research and innovation came from the Soviet model, beginning with the elite research institutes of the CAS. It has been called "the largest coordinated international transfer of technology in the history of the world." (Roy Grow). When China and the Soviet Union abruptly split in the early 1960s, China was cut off from its technology source at a time when it had no alternative technology partners and very little market access to technology. Thus, China approached a state of technology autarky for a decade from the mid-1960s through the mid-1970s. During this period, China's strategy was to import a handful of factories that embodied specific industrial technologies, and then reverse engineer and replicate them domestically. A few key technologies in metallurgy and synthetic fibers were transferred in this way, and incremental improvements were made on some Soviet-legacy technologies, such as electricity generation, where equipment was scaled up to larger more efficient units. But overall the gap between China and the world increased. Cut off from world technical progress, China had to fend for itself. In some cases, China was unable to complete the ramp-up to efficient production levels of half-finished Soviet-supplied plants, including automobiles. Isolated from the vital sources of science and technological progress, China fell further behind despite its massive technology effort.

During the reform era, China at first tried to keep government R&D outlays high, while beginning marketization in other areas. As Figure 15.1 shows, government budget outlays for science and technology stayed above 1% of GDP through 1986. But ultimately, this level of government effort was not sustainable. With government SOE revenues eroding and the budget's share of GDP declining, China could not afford this kind of technology effort. Moreover, the existing approach of often military-related R&D was under fire anyway for its low economic effectiveness. R&D was scaled back as policy-makers searched for a viable model. When the first R&D statistics become available, in 1989, they show China investing only about 0.7% of GDP in R&D, and the effort slipped further to below 0.6% in 1994. By this time, China was beginning to look like a "normal" country, with R&D outlays at or even below the level the standard pattern of R&D development would dictate. But Chinese policy-makers had no desire to be merely normal: they actively sought to raise the R&D/GDP ratio above 1%.

Fig 15.1 R&D Expenditures (Percent of GDP)

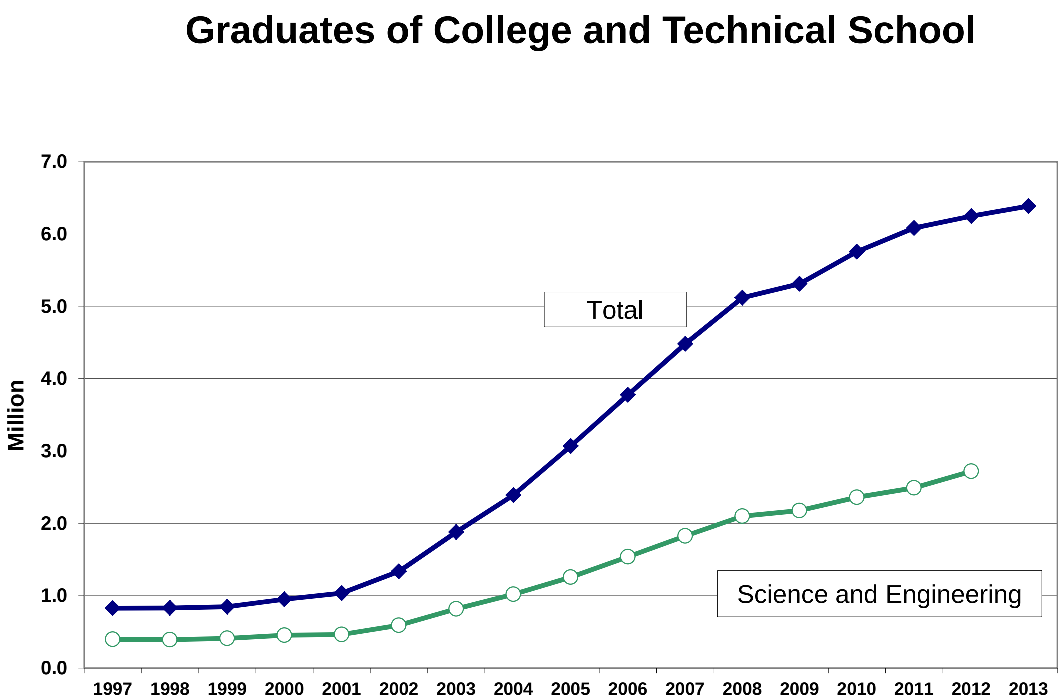


After 2000, R&D outlays in fact began to increase through numerous channels. As Figure 15.1 shows, total R&D has climbed much more rapidly than government outlays for science and technology, and the R&D ratio decisively surpassed 2% in 2013. This is a well above trend R&D effort for a country at China's level of development. A much bigger R&D effort at the enterprise level was partly responsible for the rapid increase in R&D. Even this business effort, though, was a response to a strong set of government policies that highly incentivized R&D effort. We will consider those policies in a later section.

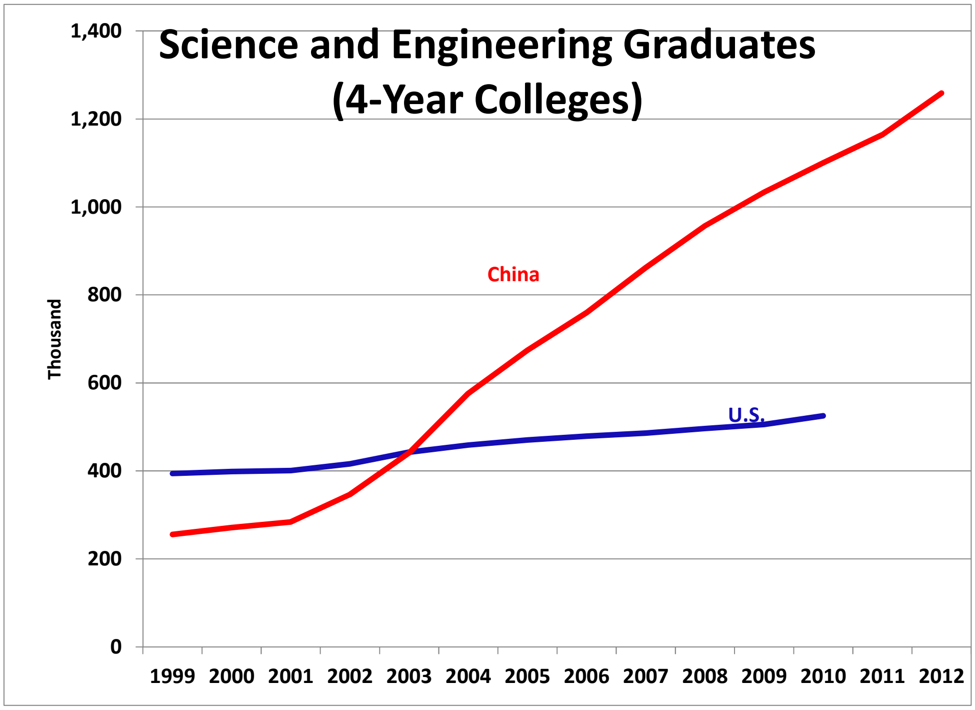
15.1.2 Human Resource Base

China's investment in science and technology human resources has also increased rapidly. Due to its enormous size, China would in any case have an impressive total stock of technical personnel. In fact, the number of individuals engaged in R&D (full-time equivalent) surpassed a million during 2003, and jumped to an almost unbelievable

3.68 million in 2013 (SAC 2005: 183; 2014: 150). China probably has more scientists and engineers engaged in research than any other country. Obviously, this growth would not have been possible without a rapid expansion in the broader human resource base. In fact, the number of annual graduates of tertiary education (colleges and technical schools) has been growing rapidly. In 1999, 858,000 college degrees were granted; in 2013, 6.39 million. Science and engineering majors make up about 45% of graduates, while economics, management and law account for another 25%. Thus, it is not simply that China's human capital base is growing rapidly: it is also growing at an accelerating rate.



Numbers like those in the previous paragraph must be used carefully. Tertiary education includes four-year colleges and three-year technical schools in about equal proportions. Three-year technical schools provide training roughly equivalent to the community college in the US: more than half the current US labor force already has such a credential. Moreover, the very rapid growth in college intake and graduation since 1999 has come at some cost in terms of average quality standards of graduates. In general, a characteristic of China's educational system is that there are many programs of adult and vocational training. Vast numbers of personnel are qualified with various kinds of technical credentials. Official statistics claim that 28 million out of 56 million state workers in SOEs and public service undertakings are qualified as technical personnel, including 12 million teachers (SAC 2005: 184). Needless to say, some of these technical credentials are at a very low level. They do, however, reflect a genuine characteristic of the Chinese technology environment, which is the presence of very large numbers of workers with some technical skills. This corresponds to the broad base of Seki's pyramid: the diffusion of these skills presents possibilities, for it suggests opportunities for technological upgrading at relatively low cost. China's factor endowments dictate that manpower is cheap, but that the human capital inputs into training manpower are scarce, and therefore expensive. The outcome is a large group of scientists and technicians, but one for which average standards are still relatively low. Still, even when due allowance is made for this effect, China is training more scientists and engineers than any country. The next Figure compares only graduates of 4-year universities in the science and engineering fields. China graduates well over twice the number as in the US.



At the top of the skills pyramid, an important role is played by Chinese who have studied abroad. China in 2001 had 124,000 tertiary level students abroad in OECD (developed) countries. Of these, 52,000 (42%) were in the US; 26% in Japan, and 21% in the EU. Official Chinese data indicate that more than 700,000 Chinese studied abroad from 1978 to 2003, and that 172,000 returned after graduation. By this account, about one in four of those who study abroad return to China. One independent study found that only 10% of Chinese Ph.D. students in the US intended to return after they received their Ph.D. Yet over the years, training of Chinese scientists and engineers in advanced degrees overseas has contributed an enormous amount to the growth of China's human resource base. First, many do return, and some return with work experience in the US or other foreign countries, which increases their value. Since about 1999, China's government has made strenuous efforts to encourage students to return voluntarily, and a booming economy has helped attract larger numbers home. Returnees have played a disproportionately large role in fostering new high tech start-ups and upgrading educational institutions. Even when students do not return, they play a role in connecting domestic scientists and engineers to international networks of research and innovation. (Schaaper 2004; SYC 2004: 781-82; “China Highlights,” Zweig 2005)

15.2 Strategies of Technology Development

Chinese policy-makers have maintained a fairly high degree of consensus around the need to invest in new technology and improve China’s technological standing. This was implicit in the trajectory of China’s R&D investment described above. However, there has been a restless alternation among different policy stances over the past fifty years:

Do It Yourself. China’s high R&D effort in the socialist period was in the classic “mission-push” mode of R&D. Leaders in China set a few key tasks and planners then coordinated flexible multi-disciplinary and multi-skilled research groups—with plenty of money—to pursue those key goals. This can work reasonably well when there is broad agreement on priorities. The objectives were achieved—two bombs and a missile—and the approach has been judged successful (Feigenbaum 1997). But this approach, in China as in the Soviet Union, was bad at transferring technology to the civilian economy. Security obsessions create secrecy barriers around the most talented scientists and engineers, even today. When planners fund research with the avowed intent of aiding the civilian economy, they are not efficient at transferring technologies. Planners don’t have the technical capabilities to evaluate the technology they have funded, so scientists are free to pursue theoretical research with very little effective oversight on the appropriateness of the undertaking. Scientists and engineers have no incentives to commercialize their discoveries, and factory managers have few incentives to seek out and implement innovations in the laboratories. High prestige research institutes affiliated with the CAS were very good at producing, for example, *one* very sophisticated computer, but their achievement ended up as a single exemplar—as a “sample, display item, or gift”—rather than as a productive resource in the economy. Isolation from world science made these draw-backs particularly debilitating.

Buy It. Market transition began at a time when China seemed to be flush with revenues from oil exports. Massive purchases of industrial machinery from technology leaders seemed the quickest route out of China’s scientific isolation. The first wave of contracts collapsed when China’s oil revenues failed to materialize, after 1978. Nevertheless, government outlays of foreign exchange for technology embodied in plants and equipment remained high. During the 1980s, US $16.6 billion was spent on technology import for existing plants, and another $30.2 billion on import for new capital construction projects (Wang Huijiong 1996; Gu Yuefang 1996). Local governments were allowed to import equipment, but the response was often excessive and duplicative import of the particular flavor of the day: Over 100 color TV assembly lines were imported in the early 1980s. Chinese policy-makers gave poor marks to this policy, since it was not effective in integrating new technologies into the economy, and it was very expensive. As China's budgetary revenues skidded during the 1980s (see Chapter 18), it was clear that China could not afford the luxury of prestige technology purchases. China today steers technology import towards "soft" technology licensing, and away from the expensive purchase of "hard" assets that embody technology. In 2003, China signed technology import contracts worth US $13.45 billion, of which $9.5 billion was for intellectual property, and $3.9 for equipment embodying technology (NBS-MOST 2004: 359). International technology purchase is today one pillar of a multi-stranded technology development regime.

Bargain for It. During the 1980s, China initiated complex negotiations with a number of large multi-national corporations (MNCs). China sought MNC technology partners, who would be rewarded with privileged access to China's market for their willingness to share technology. Often, China ambitiously targeted technology leaders as their preferred partners. Negotiations between the two sides, each with some monopoly power, often dragged on for years. MNCs were not eager to give away their most advanced technologies, and China sought highly restrictive and comprehensive deals. Ultimately, this approach led to extended negotiations, delays in implementation and disputes over how well each side was complying. Very few projects produced the massive technology transfers that the Chinese side had anticipated.

There were individual successes, though. In a recent paper, Mu and Lee (2005) argue that the joint venture Shanghai Bell Alcatel was a highly successful example of "trading market access for technology." First set up in 1984, as a joint venture with the Belgian Bell subsidiary of ITT, the purpose was to produce digital switches for telecommunications. The foreign partner was not a technology leader, and was therefore willing to agree to very generous terms in order to achieve first entrant rights to the Chinese market. The Bell Company agreed to transfer technology and to manufacture custom large-scale integrated (LSI) chips used in telecom in the Chinese facility. In subsequent years, the joint venture enjoyed the patronage of the Ministry of Post and Telecom which helped it to surmount numerous business difficulties. In return, many Chinese engineers were trained at, or rotated through, Shanghai Bell, and many were introduced to the concepts and technologies of digital telecom switches at that plant. According to Mu and Lee, this was critical to developing the expertise that was later used in the development of domestic telecom equipment enterprises, including some very successful firms such as Huawei and ZTE Telecom (discussed below). Today, this joint venture is still an important telecom supplier in China. France's Alcatel acquired the Belgian partner, and the Chinese ministry's stake was inherited by central government SASAC (see Chapter 13), making this one of the few Sino-foreign joint ventures under central government authority and reflecting its distinctive history.

Chinese policy-makers have moved away from this model of restrictive, bilateral monopoly bargaining over investment, technology and market access. In most cases, they now prefer to let numerous investors compete in the marketplace. However, policy-makers continue to drive tough technology bargains that "trade market access for technology," when they think they have sufficient bargaining power to achieve results. For example, the Chinese government has recently been in negotiation with suppliers of nuclear power facilities, conditioning large-scale purchases on the agreement to transfer technology.

Seed It. As China scaled back direct government research in the 1980s, it developed a more sophisticated system of funding research. Budget allocations to research institutes were cut, but partially replaced with a system of competitive grants. For basic science and research, institutes now prepare applications for specific funding purposes, and submit them to funding agencies, the most important of which is the Natural Sciences Foundation. Government control of research agendas is increasingly exerted through the Foundation. As part of the reorientation of national research priorities, China launched a new large-scale program to master, transfer, and diffuse key advanced civilian technologies. This program, called the "86-3 Program," after the year and month of launch, designated ten priority areas of high technology development, and encouraged the creation and funding of goal-dedicated research teams. The 86-3 Program actually involved modest amounts of government funding, which sometimes limited its effectiveness, but has generally been judged a success. The original program was succeeded eleven years later by a 97-3 Program.

In addition to the basic technological development program, a program of technology diffusion was also implemented, in various baskets. For example, the "Torch" program provides bank loans for technology adoption by enterprises, and the "Spark" plan funds technological upgrading for township and village enterprises. These programs by 2003 added up to 80 billion *yuan*, but most of the actual funding came from enterprises and bank lending. Thus, the Chinese government has become more strategic and more effective in spreading its funds among research and technology diffusion measures.

Allow Spin-offs. During the 1980s, policy-makers tried to give research institutes stronger incentives to diffuse technologies into the civilian economy. Institutes and universities were allowed to contract with enterprises to provide technical services, and were allowed to establish their own commercial subsidiaries. This permissive stance led to the creation of a number of new enterprises that became important in the development of China's high technology industry. These firms operated in a hazy area of Chinese industrial organization: although they were "owned" by the state entity that spun them off, they were considered "civilian" (*minban*), in the sense that they had no direct bureaucratic supervisor. These firms therefore had significant operational freedom, and some grew into prominent computer and IT firms such as Beijing University's Founder or Qinghua University's Tongfang. The most successful of all these firms is one that we encountered already in Chapter 13, Lenovo (originally "Legend," [*Lianxiang*]) Computer. Lenovo was spun-off from the Institute for Computer Technology of the Chinese Academy of Sciences in 1984, and it became an important presence in the burgeoning Zhongguancun high technology district in northwest Beijing (Segal 2003; Xie and White 2004). Lenovo followed an interesting trajectory: it initially developed as a commercial enterprise, acting as a distributor for foreign desktop computers. As Lenovo began to develop manufacturing capabilities, it specialized in relatively low-tech stages of the manufacturing process, notwithstanding the high technology pedigree of its parent organization. Lenovo grew by transferring much of its manufacturing operation to Guangdong, which was much more open to international trade in the 1980s than was Beijing, and concentrating on labor-intensive production of motherboards and video cards. These processes required import of components, mounting them on boards, and re-exporting, and Lenovo was successful enough to have achieved global market shares of 3% and 10% respectively by 1995. At the same time, the company became a major assembler of personal computers for the Chinese domestic market, holding a 28% market share by 2005. The company gained expertise imitating proven technologies, and concentrating on assembly stages of production. The company today aspires to move into higher technology manufacturing, and to develop a stronger research component, and characterizes its strategy as "Commerce to Manufacturing to Technology." Lenovo's takeover of IBM's personal computer division in 2004 sent a strong signal about the company's potential significance. At the same time, it demonstrated that Lenovo's core competitive advantage was focused on assembly and, perhaps, marketing of technology products. Not many spin-offs were as successful as Lenovo, but the creation of civilian spinoff firms marked a crucial stage of liberalization in China; it showed the extra latitude planners were willing to give high technology firms, and it set the stage for more comprehensive liberalization in the late 1990s.

Open up to Foreign Direct Investment. Foreign direct investment (FDI) into China exploded after 1992 (Chapter 17). Within a few years, FDI had become the predominant source of technology inflows into China. Lying behind the change was a transformation in China's attitude toward foreign-owned firms. Rather than trying to craft a few individual technology bargains, limiting entrants in order to enhance their own bargaining power, planners accepted a more general approach in which a larger number of competitive technology suppliers would be allowed in the market. Chinese policy-makers continued to envisage a general trade of “market access for technology,” but re-interpreted the terms of the deal. The result was a flood of foreign investment, much of it in medium to high technology sectors. MNCs became increasingly important technology actors in China, not only through their attempts to access the domestic market, but also because of the speed with which they knit China into global production networks of high technology items. In turn, China’s policy toward foreign investment reflected growing awareness that government-sponsored technology development programs were not leading to catch-up with the best practices of multinational corporations. As a result, Chinese economic bureaucrats and policy-makers became increasingly willing to provide market access and promises of protection of intellectual property rights to foreign multinationals if they were willing to transfer production to China. Accession to the World Trade Organization codified and made binding the promises that China was making to promote this type of technology transfer.

Support Domestic Entrepreneurship. The freedom given to domestic entrepreneurs lagged behind that accorded to foreign multinationals. It was not until 1999 that Chinese firms were given across-the-board support to enter high technology fields as private firms and start-ups. Instead of only favoring large SOEs, the government now supports virtually all technologically advanced enterprises, including small, private start-ups, and technology-intensive spin-offs from schools and research institutes. In an important shift of perception, instead of seeing private firms as rivals with publicly-owned enterprises, these firms are now viewed as “national” enterprises: non-state firms can also be the national champions that compete with foreign firms. Along with the shift in the objective of technology policy, the nature of support has changed as well. Increasingly, the government provides a kind of across-the-board support for domestic enterprises designated “high technology.” This support takes the form of tax breaks, access to low-interest credit lines, preference in procurement decisions, and other kinds of regulatory preference or relief. These policies are discussed further below.

This brief review of seven approaches to technology acquisition has shown two things. First, there has been a restless ongoing search for institutions and policies that can effectively support China’s ongoing drive to become a technology power. When a policy proves ineffective, it is dropped; new policies are constantly being tried. Second, the technology effort that China mounts today is extremely diverse and multi-stranded. “Do-it-yourself” and “Buy It” have not disappeared, but have been scaled back and mostly confined to national security areas. The other strands of China’s research effort have become more important: Broader and more inclusive technology bargains, massive interactions with multi-national enterprises, strategic support for research, and across-the-board support for domestic high technology entrepreneurs. The diversity and flexibility of China's R&D effort enhances its impact. However, since 2005, China's technology policy has shifted again, emphasizing a mobilization of resources and a "techno-industrial policy" to produce rapid results.

15.3 The Turn to Techno-Industrial Policy after 2005

Since the turn of the century, China's technological development has noticeably accelerated. China's policy toward technology development and innovation shifted dramatically after 2003. The shift in policy was carried out through two successive "waves" of policy. The first wave reached its "peak" in 2006, with the adoption of the Medium and Long Term Program of Science and Technology (hereafter, MLP), which emphasized "indigenous innovation" and provided funding for sixteen Megaprojects. The second wave reached its peak in late 2010, with the program for Strategic Emerging Industries (hereafter, SEIs). After these two peaks passed, policy stabilized. These government-directed, top-down policies interact in a complex way with another critical feature of China's high tech economy, which is it deep integration into global production networks in a way that increasingly affects research and development.

Both of these major policy initiatives involved targeting specific industries for promotion. In that sense, they represent a major movement away from the typical direction of Chinese policy up through the turn of the century. To be sure, as described above, the commitment to the improvement of technology and the development of high tech sectors has never wavered. China's economic future and, in the eyes of China's leaders, national security as well, depend long-term on technological development. However, through the turn of the century, the trend had been for policy-makers to intervene much less in the specific sectoral outcomes. Most of the large-scale government projects had been wound down by the early 21st century, and policy had focused on building human resources, strengthening Universities and research institutes, and encouraging enterprises to develop their own technological capabilities through favorable tax and other types of policies.

Table 4: Sectoral Focus of Techno-Industrial Policy

16 Megaprojects (2006-2015)		20 Strategic Emerging Industries (2010- 2020)	
		Energy Conservation and Environmental Protection	
		a.	Energy efficient machinery
1 Water pollution control and treatment	→	b.	Environmental protection
		c.	Recycling and Re-utilization
2 ULSI Semiconductor Manufacturing		**Next Generation Information Technology**	
3 Next generation broadband wireless	→	d.	Next generation internet
4 Core electronics and high end software	→	e.	Core electronic components
	↘ (from 4)	f.	High end software and information services
		Biotechnology	
5 Major New Drug Initiative	→	g.	Biopharmaceuticals
6 Major Infectious Disease Initiative		h.	Biomedical engineering
7 Genetic transformation and plant breeding	→	i.	Biological Agriculture
		j.	Bio-manufacturing Industry
		Precision and High-End Machinery	
8 Large Passenger Aircraft	→	k.	Commercial Aircraft
9 High-Resolution Earth Observation System	→	l.	Satellites and Applications
10 Manned Space Flight and Lunar Landing	↗ (to l.)	m.	Railroad and Transport Machinery
		n.	Marine Engineering Equipment
11 High-end Numerically Controlled Machine Tools		o.	Intelligent Manufacturing Equipment
		New Energy	
12 Large-bed Oil & Gas; Coal Gasification		p.	Wind Power
13 Large High-Pressure Nuclear Reactor Technology		q.	Solar Power
		r.	Biomass Energy
14-16 Three Undisclosed Military Projects		**New Materials**	
		s.	New Materials
		New Energy Vehicles	
		t.	Electric Vehicles & Plug-in Hybrids

However, at Table 4 shows, the new policy initiatives have a clear sectoral focus: this is "techno-industrial policy" in which the government seeks specific sectoral outcomes. The "Megaprojects" were an important part of the MLP, but each was selected to have a specific industrial application: they are not primarily science policy, they are primarily industrial policy. The focus, when they were put together, was on locating the R&D arenas where the spill-overs to the economy would be largest and most immediate. There is significant sectoral overlap between the Megaprojects and the subsequent Strategic Emerging Industries (SEI) program: some SEI initiatives are direct continuations of individual Megaprojects, and most Megaprojects have some relation with a subsequent SEI. Unlike the Megaprojects, which are fully government-funded, SEI development is not to be driven *primarily* by government funding. Instead, government is supposed to "make the market," creating favorable conditions for enterprises to develop and grow.

By the time the Strategic Emerging Industries (SEI) policy emerged in 2009-2010, the intellectual justification had shifted. Sectors are included in the SEI initiative because they are expected to be large and important in the future, but also because they have qualitatively new elements that have not been fully mastered anywhere in the world. Because of the absence of entrenched incumbent firms or countries, these industries are seen as providing competitive opportunities. China was undoubtedly influenced by the fact that many developed country governments—including the United States—during the global crisis of 2008-9, selected certain emerging industries for government promotion, with mixed stimulus and industrial policy motives. SEI strategy thus echoes the insight of Perez and Soete (1988) that new industries present an opportunity for leapfrog latecomer development. The SEI program is a response to a high degree of technological opportunity, combined with confidence that the returns to innovation will be appropriable, given China's ongoing manufacturing cost advantages (Cf. Breschi, Malerba and Orsenigo 2000; Lee and Lim 2001). The SEI approach is often encapsulated in the slogan: "seize the commanding heights of the new technological revolution" (Wan 2009). This approach also puts Chinese industry into direct competition with companies in the developed market economies.

15.3.1 Aligning Incentives in favor of High Technology Development

The sectoral focus of the SEIs are to be achieved through policy instruments that try to align incentives of government and corporate actors in support of the development of knowledge-intensive industry. A barrage of specific policies, some of them described here, have had a cumulative effect. While no individual policy has been overwhelmingly effective, together they ensure that actions businesses take in favor of the development of high-technology industry will meet with central government acceptance and will only rarely have negative consequences. Much of the ideological baggage that inhibited technological development previously has been abandoned. "National industry" has been redefined to include small private and hybrid start-ups, even as state-owned firms continue to have priority low-cost access to resources. Despite China's complicated and often contradictory mixture of centralized, decentralized, and quasi-federalist institutions, these enabling policies brought the incentives of many different levels of government into alignment. Localities were freed to do what they wanted to do anyway, or exposed to heightened competition from other regions if they chose not to act.

Indeed, promotion of high technology industry is arguably the central economic development policy of the Chinese government today. Technology development is the unifying thread that links together many aspects of contemporary economic policy. A newly emphatic stress on human resources as the foundation of development policy is clearly related, via the long-term development of the human capital base, to the promotion of technology industry (Cheng Li 2005). The top priority of foreign trade development has been resolutely placed on the development of high technology trade, explicitly since November 2003 (State Council Office 2003: Wu Yi 2003). Trade promotion policies stress that the key to upgrading exports is the promotion of high-tech exports, particularly those in which China has its own intellectual property. It is taken for granted that government can play a key role in promoting such exports.

Tax Breaks. A whole range of amendments to the tax code have been made to make expenditure on R&D virtually costless for the enterprise: partial tax deduction for R&D expenditures; tax exemption for all income from the sale of new technologies and related consulting services; tax exemption for imports of equipment used in R&D and not available in China; etc. The tax break that attracted the most attention, rolled out in State Council Document No. 18 of 1999, was a rebate that reduced value-added taxes from 17% to 3% for domestic software and integrated circuit producers. (This rebate was eliminated in 2005 after it was challenged by US integrated circuit companies as a violation of WTO rules).

Subsidized Credit. This includes a domestic fund to support small and medium high technology enterprises; interest subsidies for specific projects by large enterprises; and coverage of high-tech exports by the Import-Export Bank.

Procurement Preference. Domestic high-tech firms are entitled to general preference in government procurement. In some cases, government procurement policies are specifically targeted to support domestic IT development, as in the case of ID cards with embedded chips (Hsu 2004).

Corporate Governance Provisions. Greatly influenced by the success of the US "Silicon Valley model" of venture capital and start-up technology enterprises, Chinese policy-makers altered many aspects of their corporate governance procedures in order to accommodate venture capital-assisted start-up businesses. Accounting regulations on the calculation of capital were changed to allow inventions and intellectual property to be counted as investment. High technology firms were, in principle, allowed to set aside 35% of the net value of increased assets for stock options or other rewards for innovators and entrepreneurs. A small but lively venture capital industry was established, with most of the funds coming directly or indirectly from government agencies, but with a significant role for a few foreign venture capitalists as well. Provisions to allow listing of new high-tech companies on existing stock exchanges, as well as new listing venues, were rolled out in order to provide an exit option for venture capital.

Manipulating Technical Standards. Having discovered that the Chinese domestic market could support a standard for video discs (VCD) that was separate from the global DVD standard, Chinese policy-makers became very interested in using Chinese technical standards to create competitive advantage for domestic firms. Efforts have been made with next generation DVDs, third generation digital telephony, and encryption, at least, to create advantage for Chinese firms (Linden 2004; Suttmeier 2004). Whether any of these efforts has produced any benefit is not certain.

These provisions were accompanied by a farrago of subsidies that also includes lower land prices, cooperative regulatory procedures, and patient and forgiving state-financed equity investors. The government has also invested substantial funds in projects such as the creation of an indigenous central processing unit (CPU) known as Godson. Prototypes of Godson 2 and 3 were released in 2005, with processing speeds up to 1 gHz. Together, these policies increase the flow of resources into knowledge-intensive industry, and almost certainly, on balance, accelerate the development of high technology industry. Like any industrial policy, these policy interventions draw resources away from other sectors that need resources (such as agriculture), and increase profits for businessmen who do not need additional profits. However, none of these policies dramatically distorts economy-wide market signals, and the overall costs are probably fairly modest, as well as being diffused through the entire economy.

Some of these policies may be successful, but they are unlikely to be the main determinants of China's future technological trajectory. They have costs and benefits, and it is unlikely that the benefit-cost trade-off for any specific policy is dramatically positive. But at the same time, the broad array of policies strongly signals local governments that virtually any action they take in support of high technology industry and technological development will be acceptable. This insures that governmental actions at all levels are aligned in support of high tech development.

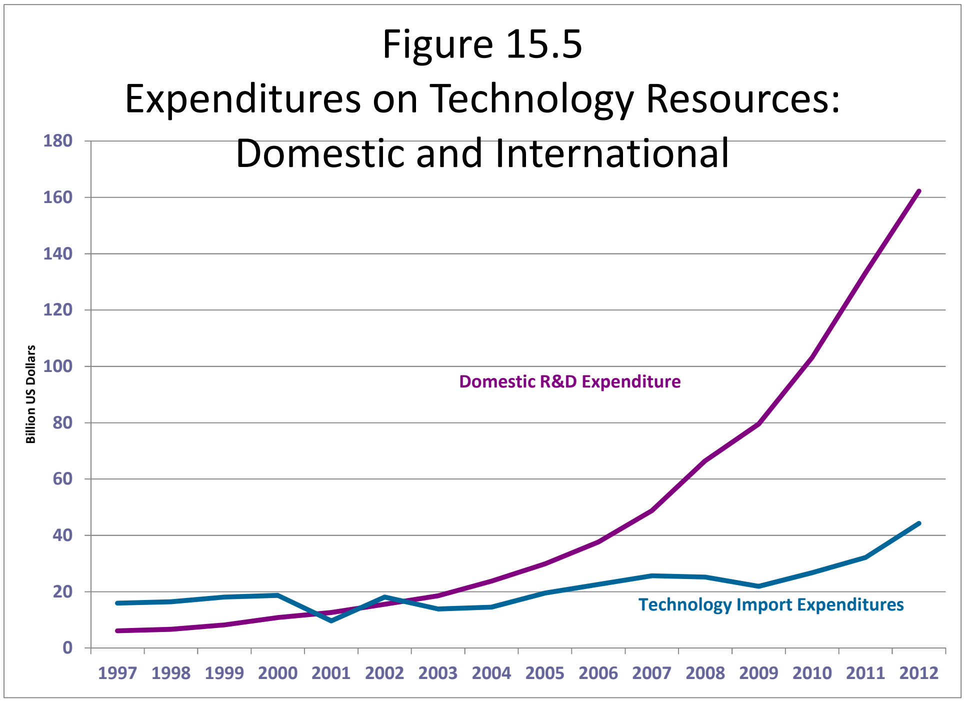
15.4 Integration into Global Production Networks

The nationalist and techno-industrial turn in China's policy after 2005 sits very uncomfortably with one of the most distinctive features of China's high-tech economy, it's deep integration into global production networks. During the 1980s and 1990s, China rapidly integrated into global production networks, taking over low-tech, labor-intensive production stages from Taiwan, Hong Kong and Korea (Chapter 17). Precisely because China specialized in the least technologically demanding stages of production, these linkages initially had few implications for technological development. Even when China was exporting finished goods that embodied high technology components—such as iPhones or laptop computers—the actual spillovers into indigenous technological capabilities were minimal. The global production networks involved in these high tech commodities were largely closed, and Chinese domestic producers did not participate much, if at all, in the high-tech part of the production chain. This spawned a dissatisfaction on the part of Chinese policy-makers and may have contributed to the willingness to turn to techno-industrial policies.

However, very rapid changes in the configuration of global production networks were already changing the nature of China's integration. Upgrading within global production networks is also an option. Multi-national firms have strong incentives to cut costs, and that implies shifting work to lower-cost domestic firms if they can do it more cheaply. In the old days of the 1990s it was primarily low technology stages of the manufacturing process that were "outsourced," because these were the only labor-intensive stages of the production process that could be easily relocated to labor abundant locations such as China. However, today, processes of vertical specialization, or "modularity," have progressed further than in the past, and are beginning to transform manufacturing, services, and innovation in more profound ways. Some stages of production, services, or even research can be incorporated into modules that can be partitioned off from the rest of the value chain. The results of the work or innovation within the module can be summarized through a mutually accepted interface standard, so that downstream firms can use the results of the previous module without knowing what went on "inside" the module. This enables firms to pursue focused strategies that rely heavily on outsourcing across the value chain. These changes have important implications for China's technological development. The same trends that led firms to slice up and relocate the manufacturing value chain are now increasingly coming to bear on the services embedded in the high technology value chain, including research and development. Businesses are gaining more experience with international cooperation and offshoring; the cost of communications continues to fall. Meanwhile, manufacturing is a smaller part of the total value chain than it was before, and the increase in manufacturing sophistication has increased the demands on design and other capacities. As a result, there are many more opportunities to "outsource" knowledge-intensive services, such as software, engineering and R&D. These activities then provide a new pathway to technological upgrading, as design teams expand the scope of their competence. A similar process is at work in R&D centers: development tasks that can be routinized and formalized will ultimately be transplanted to China to a significant extent.

These changes are creating new models of international cooperation. Heretofore, the most widely accepted interpretation of East Asian technology development has been the "international subcontracting" model (Sharpston, 1975). In this model, drawn largely from Taiwan and Korean experience, firms begin by subcontracting for manufacturing (OEM, or original equipment manufacturing), gradually expand capabilities "upstream" to include design and some supply management (ODM, or original design manufacturing), and then launch their own brands (OBM, or orginal brand manufacturing) as they become architects of entire systems (like Samsung) (Hobday, 1995; Ernst and O'Connor, 1992). But modularization is creating a new model in which the value chain is more and more finely divided and firms specialize in narrower and narrower slices. Successful firms no longer simply "move up the value chain" from

OEM to ODM to OBM, but instead specialize in specific links of the value chain, and then combine them in ways that create competitive advantage. Lenovo Computer is a perfect example: it is not a manufacturing powerhouse moving up with the IBM brand, as many have assumed. Instead, Lenovo is a strong domestic brand, with a diverse mix of manufacturing and technological development skills. In fact, in 2003 Lenovo outsourced 100% of its laptops, 70% of its PDAs, and 40% of its motherboards to Taiwan contract manufacturers, thus turning the "international subcontracting" model on its head (Jiang 2004). Increasingly complex business strategies based on an increasingly fine division of the value chain: this will create the most important points of contact at which advanced technology can spill over from world technology leaders to Chinese firms.



China's new policies represent a step away from this model of technological upgrading. The emphasis on domestic investment and domestic firms inevitably implies a de-emphasis of the opportunities of technology import. Figure 15.5 shows that China has moved dramatically away from a technology import model. As late as 2004, total domestic outlays for R&D were about the same magnitude as technology import expenses. Indeed, domestic outlays were probably too low to take full advantage of technology import opportunities, which require substantial complementary expense on adaptation and training to really achieve full value. Regardless, in the decade since, domestic outlays have more than quadrupled, while technology import expenditures have just doubled. This is a clear reflection of policy emphasis.

The trade-off between domestic and international expenditures is also related to the utility of intellectual property policy. Close cooperation and trust are necessary to exploit upgrading opportunities in a global industry. Again, this is exemplified by the IC industry. The production of any significant IC requires literally thousands of pieces of intellectual property. No developing country, including China, can ever hope either to "invent around" existing intellectual property, or license each essential piece of intellectual property at market rates. Indeed, no existing company, not even Intel or TSMC, could produce without access to intellectual property owned by competitors. Typically, the industry proceeds by various kinds of cross-licensing agreements. Various formulas—and sometimes significant hard bargaining—are used to work out the relative value of the intellectual property on each side, and a net financial flow from one company to the other determined on that basis (Teece 2000). This presents China with two very large challenges. The first is to strengthen its protection of intellectual property rights, so that it can become a full partner in cooperation with MNCs in high technology industries. The second is to develop enough bargaining power such that Chinese firms have something to offer MNCs in exchange for their IPR. A few multinationals have begun to share their IPR with China's nascent IC firms, so a beginning has been made. Increasingly, the focus of Chinese government technology policy is on created bargaining capital for China's high tech industry, in order to improve China's standing in the exchange of technological information along global production networks.

15.5 Conclusion

The pace of technological change in China is likely to accelerate. As we have seen, China has now mounted a substantial technology effort that works through diverse channels. Policy-makers have been flexible and adaptive in their approaches. The human resource base is now growing rapidly, from a relatively low base, and this growth shows every sign of accelerating. The institutions and incentives that support technology adoption have changed very dramatically in just the last 5-6 years, and now provide abundant rewards not only for technology pioneers, but also for those who implement improved technologies effectively. These changes are occurring in a context in which China is moving away, at the margin, from close cooperation with multi-national firms. The resulting prospect is one of rapid rise but also increased friction around a variety of industrial and technological issues.