15 Technology Policy and the Knowledge-based Economy

What will China become during the twenty-first century? Previous chapters on the development process have shown that inputs into production in China are growing rapidly. China's manpower resources are vast and growing, and becoming healthier and better educated. The high saving and investment rates, combined with the rapid buildout in physical infrastructure, provide the physical capital needed for sustained growth. Economic policy has been well-crafted generally, enabling China to benefit from domestic market transition and international opening. By midcentury, then, there is no doubt that China will emerge as one of 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? Will China become a global center of innovation, joining the ranks of developed countries and the emerging East Asian centers of technological creativity?

These questions will be decided by the pace at which China adopts, adapts, and transforms the world's body of science and technology. Effective adaptation of technology will sustain rapid growth by increasing the productivity with which inputs are converted into output. Fast growth of inputs combined with a continuous increase in technology-driven productivity will be necessary if China is to sustain rapid growth over the coming decades. Moreover, it is not merely that the growth of output, in a mechanical sense, equals the growth of inputs plus the growth of productivity. In China today, there is a massive pool of talent and ingenuity that has only begun to be tapped. When the potential of this underutilized resource is finally realized there will be a global impact.

More economically effective utilization of knowledge is a step on the road to an increasingly creative and innovative society. Perhaps no issue more effectively unites policymakers, business leaders, and the public today in China than the desire to propel China into a high technology future.

China's technical capabilities today, however, are still quite mixed. Seki Mitsuhiro (1994) suggested 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. Today 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 has 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, or 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; cf. Liu and White 2001). Both the technology effort and the growth of the human resource base contribute to accumulating knowledge, while institutions and incentives determine how much of the knowledge will be applied in the production arena. These two aspects—generating and applying knowledge—are two sides of the technology picture; the ability to apply knowledge is at least as important, in an economic context, as the technology effort or resource base, but more difficult to measure and assess. Section 15.1 examines the technology effort, starting with the size of the R&D commitment, and moving on to the strategic evolution of R&D policies. Section 15.2 examines the recent growth of the human capital base, while available evidence on the outcome of the technology effort is considered in section 15.3. The focus then shifts to the type and adequacy of the institutions that shape technology decisions today. The renewed commitment and consistency of the government's technology development policy that has emerged since the turn of the century is the focus of section 15.4. The other major factor determining technology upgrading is the nature of interactions between domestic firms and multinational corporations, which is the subject of section 15.5. It is these institutions—and particularly the interplay among government, foreign multinationals, and domestic high-technology firms—that will be crucial in determining whether China will make a rapid jump to a high-technology economy.

15.1 PURSUING CRITICAL TECHNOLOGIES: THE R&D 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. The success of Japan and Korea was particularly striking in that both sharply restricted direct investment by foreign companies.

In contrast to Japan and Korea in the 1970s, most developing countries today welcome foreign direct investment (FDI), largely because of their recognition of the difficulty of domestic technology development. The hope is that foreign investors will build sophisticated 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. Thus, although China runs an aggressive, sustained and multifaceted policy of promoting domestic technology, it does so in a context of economic openness. Chinese policy-makers are tempted to emulate past Japanese or Korean technology and industrial policies, but their policies and their effectiveness end up being quite different because of the different economic environment and different relationship with multinational technology companies. The greater openness to FDI is a characteristic of the global environment that China has fully embraced.

Whatever the global environment in which a country operates, it must invest resources in research and development in order to discover and adapt new, more productive technologies. R&D spending by successful developing countries follows a systematic pattern. Low- and lower-middle-income economies spend relatively little on R&D, typically less than 1% of GDP. Since it makes no sense for them to reinvent the wheel, they spend modest sums overall, and most is focused on the identification and adaptation of foreign technology. 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 that a technological effort of this magnitude is required to remain at the technological frontier. Some of the comparative figures are given in Table 15.1. China, with 1.1% of its GDP going to R&D in 2003, fits in this general pattern. 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, China is about where we would expect. By another measure—researchers per 1,000 employment—China is much further back, reflecting the still large labor force in the traditional agricultural and service

Table 15.1
Comparative indicators of R&D activity

	R&D outlays (percent of GNP)	Researchers per thousand total employment
China (2003)	1.1	1.2
Mexico (1999)	0.4	
Brazil (2000)	1.1	
India (2001)	0.9	
Taiwan (2003)	2.5	7.1
Korea (2003)	2.6	6.8
All OECD (2000)	2.2	6.6
France (2002)	2.2	7.5
United States (1999)	2.6	9.3
Japan (2003)	3.2	10.4
Sweden (2001)	4.3	10.6

sectors. Size matters: taking everything into account, China has the world's fourth-largest R&D effort, after the United States, Japan, and the European Union. Figure 15.1 graphically summarizes the data on proportional and absolute technological effort. China's importance will rise as the size of its overall economy grows and as the share of the economy going to R&D increases. The figure also shows the significance of Korea and Taiwan, important technology powers that carry substantial weight on the global technology stage.

15.1.1 The Trajectory of China's Technology Effort

Paradoxically, 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 (the only R&D data available 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 intercontinental missiles. The big effort was completely consistent with the command economy and Big Push strategy described in Chapter 3.

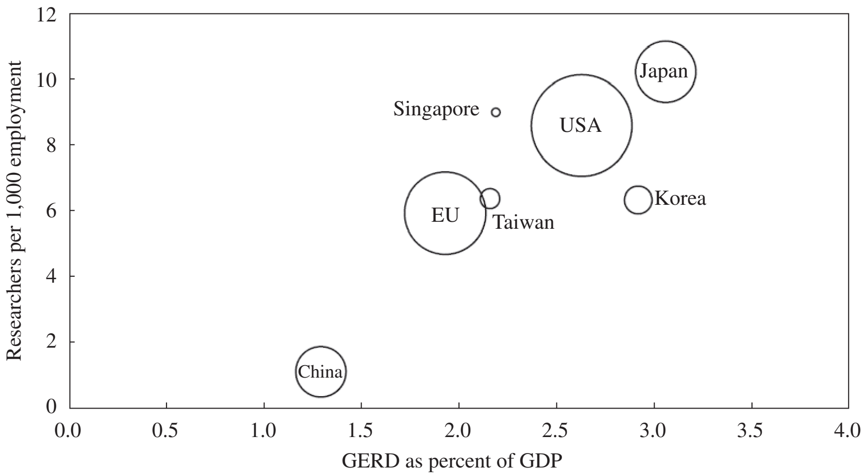

Figure 15.1
R&D efforts in selected economies, 2001. The size of the bubble represents the amount of R&D expenditure in current PPPs. GERD, gross expenditures or research and development.

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. This was probably the largest coordinated transfer of technology across national borders ever known. Subsequently, 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 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 factories, including automobile plants. Isolated from the vital sources of science and technological progress, China fell further behind despite its massive technology effort. Anxiety over the widening technology gap was a major motivating force for China's opening.

During the reform era, China at first tried to keep government R&D outlays high, while beginning marketization in other areas. As Figure 15.2 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 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 showed 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%. After 2000, R&D outlays in fact began to increase

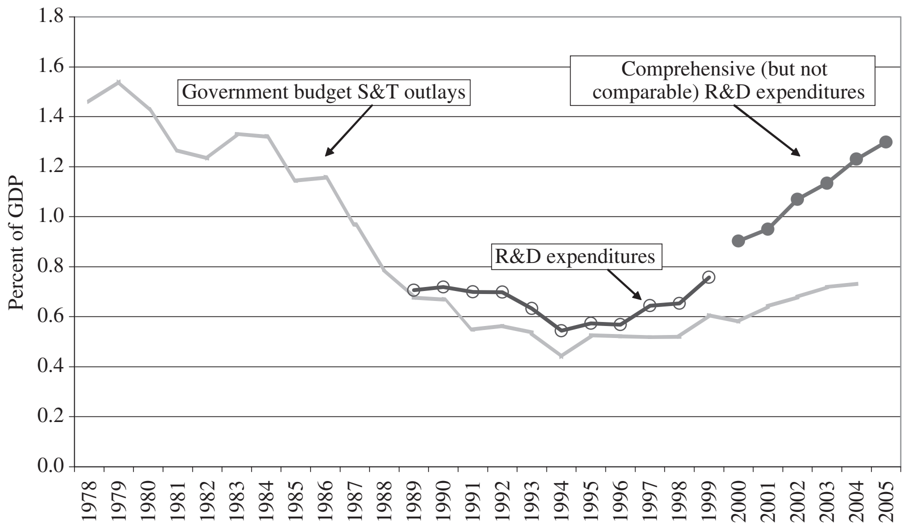

Figure 15.2
R&D expenditures (percent GDP)

through numerous channels. As Figure 15.2 shows, total R&D has climbed much more rapidly than government outlays for science and technology (S&T), and the R&D ratio reached 1.3% in 2005. This is a strong but appropriate R&D effort for a country at China's level of development. A more inclusive survey of business R&D was partly responsible for pushing up the overall rate of reported R&D, but this seems to have been a case of the statistical system belatedly catching up with a real trend, the diversification of research channels. The next section considers the way in which specific R&D strategies and policies interacted with the overall R&D effort.

15.1.2 Strategies of R&D Investment

Chinese policy-makers have maintained a high degree of consensus around the need to invest in new technology and improve China's technological standing. However, the means used to achieve this goal have varied substantially over the last 30 years. For convenience, the varying policies are grouped into seven approaches in the following subsections.

15.1.2.1 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 multidisciplinary and multiskilled research groups—with plenty of money—to pursue those key goals. This worked well when there was broad agreement on priorities, and the objectives—two bombs and a missile—were achieved (Feigenbaum 1999). 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 do not 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 shortcomings particularly debilitating.

15.1.2.2 Buy It

At the beginning of China's opening (1978), massive purchases of industrial machinery from technology leaders seemed the quickest route out of China's scientific isolation. China seemed to be flush with revenues from anticipated oil exports. The first wave of contracts collapsed when China's oil revenues failed to materialize after 1978. Nevertheless, the government spent a lot for technology embodied in plants and equipment. During the 1980s, US$16.6 billion was spent on technology imports for existing plants, and another $30.2 billion on imports 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 importation of the particular flavor of the day: More than 100 color TV assembly lines were imported in the early 1980s. Chinese policy-makers later gave poor marks to this policy because it was very expensive and ineffective in diffusing new technologies into the economy. As China's budgetary revenues skidded during the 1980s (see Chapter 18), China could no longer afford the luxury of prestige technology purchases. China today steers technology import toward "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 only $3.9 for equipment embodying technology (NBS-MOST 2004, 359). International technology purchase is today one pillar of a multistranded technology development regime (Feinstein and Howe 1997).

15.1.2.3 Bargain for It

During the 1980s, China initiated complex negotiations with a number of large multinational corporations (MNCs). China sought MNC partners, who would be rewarded with privileged access to China's market in return for sharing technology. China ambitiously targeted world technology leaders. 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 protracted negotiations, delays in implementation, and later disputes over compliance. 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 venture had as its purpose the production of 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 training 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 in section 15.3). 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 that were under central government authority and that reflected 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.

15.1.2.4 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. A new program to master, transfer, and diffuse key advanced civilian technologies, called the 86–3 Program, after the year and month of launch, designated 10 priority areas of high-technology development. Goal-dedicated research teams were encouraged and funded, although dispersion of funding sometimes limited effectiveness. The 86–3 Program has generally been judged a success, and it was succeeded 11 years later by a 97–3 Program.

In addition to basic technology development, 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 RMB, 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.

15.1.2.5 Encourage 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; they were also 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 importing components, mounting them on boards, and reexporting, 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. Not many spin-offs were as successful as Lenovo, but the creation of civilian spin-off 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.

15.1.2.6 Open Up to 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 they reinterpreted 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 had not led to catching up with global best practices. 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 WTO codified and made binding the promises that China was making to promote this type of technology transfer.

15.1.2.7 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. In place of the earlier policy 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, instead of seeing private firms as rivals with publicly owned enterprises, these firms are now viewed as "national" enterprises: nonstate firms can also be the national champions that represent China in the global market place. The nature of support for high tech firms has changed as well. Increasingly, the government provides a kind of across-the-board support for domestic enterprises designated "high technology." Tax breaks, access to low-interest credit lines, preference in procurement decisions, and other kinds of regulatory preference or relief are all used and are discussed further in section 15.4.1.

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 multistranded. "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 multinational 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 (Naughton and Segal 2002).

15.2 HUMAN CAPITAL RESOURCE BASE

Chapter 8 describes the general improvement in educational standards in China; this section focuses on technical personnel. Because of its enormous size, China has an impressive total of technical personnel, reporting a total of 1.16 million individuals engaged in R&D (full-time equivalent) in 2004, of whom 920,000 were scientists or engineers (*SAC* 2005, 183). These numbers have grown at 5% annually since 1995 (6.5% for scientists and engineers). At this rate, China will have more scientists and engineers engaged in research by about 2015 than any other country. The number of annual graduates of tertiary education (colleges and technical schools) has also been growing rapidly. In 1999, 858,000 college degrees were granted; in 2005, 3.07 million. Science and engineering majors make up about 45% of graduates, while economics, management, and law account for another 25%. Since 2004, then, China has been turning out a million graduates per year with science or engineering training (Figure 15.3). Thus it is not simply that China's human capital base is growing rapidly: it is also growing at an accelerating rate.

However, numbers like those in the previous paragraph must be used carefully. Three-year technical schools, which provide training roughly equivalent to the community college in the United States, accounted for 43% of graduates in 2004. These graduates have skills and training, but should not be classified as engineers. China's educational system includes many programs of adult and vocational training, so 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 have some kind of certification including 12 million teachers (*SAC* 2005, 184). Some of these technical credentials are at a very low level, but they reinforce the picture 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 in the workplace. 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.

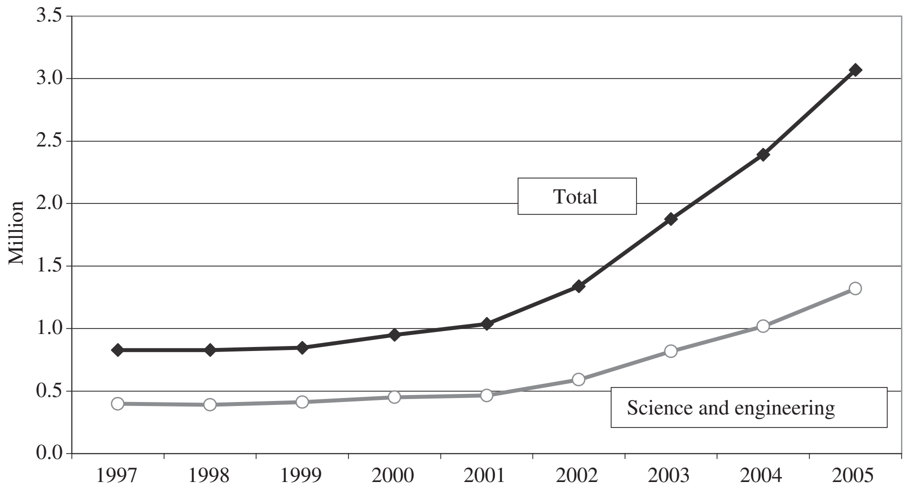

Figure 15.3
Graduates of college and technical school

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 United States, 26% in Japan, and 21% in the European Union. 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 PhD students in the United States intended to return after they received their PhD. 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 United States 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" 2004; Zweig 2005).

Figure 15.1 showed the size of the total R&D effort converted at PPP rates. By this measure, China's aggregate R&D effort is substantially larger than that of Korea and approaches Japan's in total size. However, if we were to convert at official exchange rates, the value of the total Chinese R&D effort would be less than that of Korea and a small fraction of Japan's. Which is more appropriate? The PPP estimate picks up the much lower cost of skilled manpower in China, but the official exchange rate picks up the fact that most of the high-quality inputs needed in R&D must be imported and paid for at world prices. The truth thus lies somewhere in between. The Chinese effort is large, but it is less effective than in some other countries because of China's overall lower level of development.

15.3 THE OUTPUT OF THE R&D EFFORT

China's R&D effort was dominated by government research institutes for many years. Government research accounted for two-thirds of total R&D expenditure through the 1980s. The concentration of research in government institutes limited the economic effectiveness of R&D, while also making it difficult for us to assess that impact. This concentration of research in government facilities was in sharp contrast to market economies, where typically two-thirds of the researchers, as well as more than two-thirds of the R&D money, are in the business sector. In recent years, though, the share of R&D performed by Chinese enterprises has increased dramatically. An R&D census conducted in 2000, permits us to estimate shares of total R&D. The 2000 numbers found that 60% of total R&D activities were carried out in the enterprise sector, and this figure increased slightly to 62% in 2003. In terms of personnel, the enterprise sector had 50% of the R&D personnel in 2000 and 60% in 2003. Thus the data indicate that Chinese firms now account for about the same share of R&D outlays as their counterparts in market economies.

The increase in the share of total Chinese R&D undertaken by businesses may be somewhat less than the data indicate, though. In the first place, a large number of research institutes were converted into enterprises during 1999–2001. Some became stand-alone service providers, and many were amalgamated into the new industrial corporations that were being carved out of the state bureaucracy at this time. But many institutes have had difficulty redefining their mission to accord with a business perspective, and many institutes that were amalgamated subsequently declared independence and set up shop on their own (Hu Jiayuan 2005). Further, the Chinese government has recently rolled out an impressive array of tax incentives and support for R&D in the business sector: We should assume that enterprises have responded to these policies by classifying and reporting more activities than before as R&D, even before they actually increase R&D activities.

However, more detailed econometric work finds that Chinese enterprise-level R&D expenditures have a significant effect both on firm-level productivity and on the firm's ability to absorb technology. Hu, Jefferson, and Qian (2005) found that firm R&D outlays and foreign technology transfer are complements, and both are significant in explaining firm performance. Moreover, using the same data set, Fisher-Vanden and Jefferson (2005) found that firm-level R&D had a statistically significant effect in inducing firms to adapt existing technologies to shift toward more labor-intensive and capital- and energy-saving technologies. This finding presents strong evidence that businesses use R&D to develop production technologies that utilize China's abundant factors and economize on scarce factors, thus saving businesses money. In addition, there is no doubt that a few top information technology (IT) companies in China have begun to invest significantly in R&D. Huawei and ZTE, for example, the top telecom equipment firms referred to in section 15.1.2.3, report spending 14.7% and 7.6% of gross revenues, respectively, on R&D.

The pace of patenting in China has grown strongly and steadily. In 2003 more than 300,000 patent applications were submitted. This number, however, includes "utility models" and design patents, which are relatively modest adaptations of existing technologies. If we limit our scope to the 105,318 applications for new inventions, we find that almost half (48,549) of those applications were from foreigners and over half (56,769) were from Chinese citizens. Clearly the patent system is beginning to play a role in the strategies of foreign companies in China, which increasingly seek to protect intellectual property whatever the source. At the same time, Chinese inventors are beginning to find it worthwhile to start protecting their own intellectual property. Another piece of evidence comes from the changing behavior of MNC affiliates in China. Affiliates of U.S. multinationals in China have begun spending significant amounts on R&D. Affiliates of U.S. companies in China report spending 9.2% of their value added on R&D, significantly greater than the average rate of 3.3% for U.S. affiliates in all overseas locations (NSF 2004). This expenditure is very unusual, because it makes China the only developing country in which U.S. overseas affiliates conduct a significant amount of research and development.

The most apparent China differences in the distribution of R&D effort are outside the business sector. The share of government research institutes has declined, but in 2003 they still accounted for 19% of the personnel and 26% of the expenditures on R&D. Universities, however, account for 17.3% of the personnel and 10.5% of the expenditure. This is the reverse of the proportions of government and universities in most other countries. Government research typically accounts for around 10% of total R&D, and universities often account for 20% or more of total R&D. Thus China's R&D effort is characterized by relatively a strong government sector, a relatively weak university sector, and a still immature business R&D effort.

15.4 REDEFINING GOVERNMENT TECHNOLOGY POLICY IN THE TWENTY-FIRST CENTURY

Since the turn of the century, China's technological development has noticeably accelerated. Part of the acceleration may be due to the increase in R&D inputs attributable to government policy, and some part may also be due to the beginnings of a Chinese corporate sector with the ability to invest in R&D. Government policy shifts play an important role. For decades into market transition, China's government pursued various flavors of "industrial policy." Industrial policy targeted priority sectors, picked winners among firms (typically SOEs), and tried to compensate for distortions in the emerging market environment (Lu and Tang 1997; Marukawa 2000). Today, industrial policy has increasingly been subsumed into technology policy. The instruments have diversified, but the ultimate objective has become much more focused than in the past.

15.4.1 Aligning Incentives in Favor of High-Technology Development

Since 1999 technology policies have achieved a thorough alignment of 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 taken in favor of the development of high-technology industry will meet with central government acceptance and will only rarely have negative consequences. First, post–1999 policies enable technological development because they abandoned much of the ideological baggage that had inhibited technological development up to that time. "National industry" was redefined to include foreign-invested firms and small private and hybrid start-ups, and national planners thereby removed many ideological obstacles to creative organizational approaches. Second, by greatly relaxing their effort to condition approvals of individual foreign investment projects on specific technology transfer, planners actually enabled much more rapid technology transfer. Thus, 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 economic policy in the Hu Jintao–Wen Jiabao administration (2002–). A newly emphatic stress on human resources as the foundation of development policy is clearly related, by way of the long-term development of the human capital base, to the promotion of technology industry. The top priority of foreign trade development has been placed firmly on the development of high-technology trade. 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, and it is taken for granted that government has a role in promoting such exports. In the sphere of corporate governance, as argued in Chapter 13, high-technology enterprises have been at the cutting edge of changes that give managers stakes in the firms they run. Finally, there is technology policy per se, in which an enormous range of subsidies and financial support packages are available to literally thousands of private, state-owned, and foreign-invested firms. The following points give the flavor of some of these provisions:

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; and so on. 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 U.S. integrated-circuit companies as inconsistent with WTO rules.)

Subsidized Credit. Subsidized credit 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 smart ID cards with embedded chips.

Corporate Governance Provisions. Greatly influenced by the success of the U.S. "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.

Manipulation of 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 and Yao 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 approach insures that governmental actions at all levels are aligned in support of high-tech development.

15.5 DEEPER 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 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. This history has spawned a realistic pessimistic literature about Chinese capabilities, based on the combination of observed concentration on low-technology stages of the value chain and observed weaknesses of Chinese corporations (Nolan 2002; Steinfeld 2004; Gilboy 2004; Cf. Rosen 2003).

The pessimistic literature highlights some of the real shortcomings of Chinese technological capabilities. However, very rapid changes in the configuration of global production networks make it unlikely that these backward-looking assessments will be very good guides to the future. In the first place, we already see a few selected industries where undeniably "high-tech" stages of production are moving to China. For example, the integrated circuit (IC) industry exemplifies nearly all the factors discussed in this chapter. For years, China attempted to nurture a domestic IC industry without succeeding in narrowing the technological gap behind world technology leaders. From 2001, though, China's more inclusive technology-promotion policies began to succeed in attracting joint-venture IC factories to the mainland. The most prominent of these firms, Semiconductor Manufacturing International Corporation (SMIC), rapidly shrank the gap with global technology leaders to less than two years, an impressive performance in this extremely dynamic industry. Without doubt, very substantial tax breaks and implicit subsidies were an important part of this process. Expertise from Taiwan and finance from diverse international sources were instrumental in the creation of what has become a flagship firm in China's "national industry." Despite the role of policy in encouraging a Chinese IC industry, it is clear that economic fundamentals had to be in place before the policies could bear fruit. China has already developed a huge demand for ICs as a result of the development of large telecommunications-equipment, personal-computer, and consumer-electronics industries. Indeed, even after robust recent development, China's domestic IC firms still supply a mere 16% of total domestic consumption. This robust demand enabled specific promotion policies to succeed.

The IC industry can also illustrate some of the more general changes occurring in the organization of global production networks. 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 capability 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. In the IC industry, improvements in semiconductor manufacturing productivity have been so rapid that they have exceeded the pace of technological progress in semiconductor design and related services. As semiconductor design becomes more of a bottleneck, the pressures to reduce its cost increase, and entrepreneurial businesses are more likely to find solutions that involve a China design component (Ernst 2004). Integrated-circuit design is now broken up into modules, and some of the work—initially the most routine and formalized—is outsourced to China. Design building blocks are modules that can be created and improved by one team, then assembled and reassembled in ever more complex packages by other teams of chip designers. Tiny IC design houses are thriving in China, and some MNCs locate design shops in China to take advantage of low-cost engineering talent. Modularization, in short, allows China to specialize in labor-intensive activities that also involve medium levels of engineering skill, which it has in abundance. 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.

At the same time, Chinese domestic firms are utilizing international networks in their own ways. As Liu Xielin (2005) points out, many Chinese firms seek access to global technology at the cheapest cost, and combine it with their own capabilities to serve the Chinese market. Liu uses the mobile phone handset industry as an example: Chinese handset manufacturers purchase components that embody advanced technology (especially the ICs at the core of the phone's function) and assemble them into products adapted to the demands of the local market. This manufacturing is not initially a high tech process, but rather one closely adapted to market demand. However, Liu finds that as product design capabilities improve, the domestic industry has rapidly expanded its technological capacity as well. Lenovo Computer is another 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 personal digital assistants (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 are based on an increasingly fine division of the value chain; this process will create the most important points of contact at which advanced technology can spill over from world technology leaders to Chinese firms.

However, the re-creation of global value networks requires new cooperation around intellectual property. Close cooperation and trust are necessary. 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 to license each essential piece of intellectual property at market rates. Indeed, no existing company, not even Intel, 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 is determined on that basis (Teece 2000). This situation 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 creating 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. It is a process that has just begun, but it promises to transform China's technological capabilities.

15.6 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 five or six years and now provide abundant rewards not only for technology pioneers, but also for those who implement improved technologies effectively. These changes are all occurring in a global context in which increasingly close cooperation and increasingly fine divisions of the value chain are rapidly leading to the relocation of technology-intensive services. These changes work strongly to China's advantage, and it appears that China has the human resource capacity and the institutional framework that will allow it to take advantage of the opportunity.

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Suggestions for Further Reading

There is vigorous discussion between optimists and pessimists about China's technological development, and this discussion is a good place to begin. Optimists focus on China's rapid improvement and on the creation of a coherent set of institutions to foster technological process. See, for example, Suttmeier and Yao (2004) and Liu Xielin and White (2001) for good analytic overviews with an optimistic tone. Pessimists (Gilboy 2004; Rosen 2004; Steinfeld 2004) focus on China's still low overall level and the limitations to the capabilities developed by Chinese firms. Fischer and von Zedtwitz (2004) put the discussion in temporal perspective. Liu Xielin (2005) is an interesting piece that puts forward a new paradigm of open cross-border networks. Book-length studies of specific industries include Lu (2000) on computers and Shen (1999) on telecom equipment.

Sources for Data and Figures

Figure 15.1: Schaaper (2004).

Figure 15.2: Technology Statistics Office (1990, 202–03); NBS-MOST (2004, 2); *SYC* (1998, 716); and NBS-MOST (Annual) and *SYC* (Annual).

Figure 15.3: *SYC* (2005, 697) and earlier volumes.

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Table 15.1: OECD (2005, 18, 21, 57); NBS-MOST (2004). Recalculated with revised GDP data.

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