Introduction

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Mainland China is the world's second-largest producer of electronic and information technology (IT) products, after the United States. In 2006 its high-tech exports were a remarkable $342 billion, up $80 billion from 2005. That one-year *increase* is almost the equal of Chile's *total* national output. No wonder it is said that China is taking over world manufacturing.

However, much reporting misleads on China's high-tech trade. Did China really "make" $342 billion of these products in 2006? In reality, its IT industry is part of a global supply chain in which components (such as microprocessors, screens, disk drives, and memory chips) are shipped from Japan, Taiwan, the United States, Korea, and elsewhere, assembled on the Mainland, and then (mostly) exported. The value of its imports in this global system is about 75 percent of the value of exports, with the difference being the value added in China.[1] So China added approximately $85 billion of value in 2006. That is still an impressive number, but less than that added by Japan, the fifteen original members of the European Union (EU-15), and the United States (also in 2006).

The story is similar on integrated circuits (ICs). China's IC "consumption" reportedly went up fivefold from 1999 to 2005—reaching $56 billion, or one-fourth of global output. But much of that wasn't really consumption. Two-thirds of these chips were imported and then promptly exported in assembled goods. Although its domestic IC production is growing rapidly, China is likely to remain by far the world's largest importer of semiconductors for many years to come—and to continue to be a large exporter of them in finished products.

An interesting analysis has recently been published on where value is added on the iPod.[2] Most striking is the finding that of its $150 factory cost, which is recorded as contributing $150 to the U.S. trade deficit with China, only about $4 of value is actually added there. Further, of the iPod's $299 retail cost, Apple (especially) and other American firms captured most of the value. It is not only Apple's brand that is of value here but its conception of the system that comprises the iPod, iTunes, and computers.

China's pattern of production is similar to that of late-developing countries, at least in Asia. At first, their main advantage is in low-cost labor and their main challenges are acquiring technologies from abroad, developing management skills, and learning about world markets. The focus is on reducing costs by adopting better manufacturing processes; domestic companies often produce for foreign firms on an original equipment manufacturing (OEM) basis. With experience, more attention is paid to improving products for global and domestic markets, if the latter are large enough. This leads to original design manufacturing (ODM), in which design activities that had been performed by downstream, overseas, buyers are gradually assumed by the (formerly) OEM suppliers. Some of them "orchestrate" products in the sense that they play a larger role in conceiving their designs and managing their supply. An increasing number of Taiwanese firms have reached this stage. Eventually, some firms make the transition to original brand manufacturing (OBM) and become known to consumers globally. Taiwan's Acer (the world's second-largest desktop PC seller in the fourth quarter of 2006) has achieved this status. China's Lenovo jump-started the process by buying IBM's PC business, an event that Dieter Ernst discusses in chapter 11 of this book. Likewise, Haier products are being marketed around the world.

The histories of Taiwan and Hong Kong are instructive. Taiwan went down the path of becoming a leading manufacturer of IT products (among others) based on links with multinational corporations (MNCs) in the developed countries, especially the United States. It set up an industrial structure with many fast-reacting, competitive manufacturers—one that differs markedly from those of Korea, Hong Kong, Singapore, and the Mainland, with its many state-owned companies.

Rising wages then led Taiwan's companies to move their manufacturing operations to the Mainland. This has produced what has been called, with some oversimplification, the "Silicon Triangle," with nodes in Silicon Valley, Hsinchu, and Shanghai. Several chapters of this book deal with these linkages, and Kung Wang and Yi-Ling Wei explicitly deal with the "Triangle" in chapter 7. In 2003 Taiwanese firms accounted for 90 percent of China's $41 billion in exports of computers, components, and peripherals, and 70 percent of its exports of electronics and telecommunications equipment. In chapter 4, Douglas Fuller discusses the important role of "foreign-invested enterprises" (FIEs) in China, many of which are Taiwanese.

Hong Kong evolved very differently. Twenty years ago it was home to IT-manufacturing activities, but high wages and land costs made it uncompetitive as a manufacturing hub. It evolved instead into a major financial center, based on the crucial advantage of operating under the rule of law, and acquired skills in managing supply chains, acting as a middleman between low-cost manufacturing sites in nearby Guangdong and distributors worldwide. In chapter 18, Erik Baark discusses the case of Hong Kong, arguing that the special administrative region (SAR) should view innovation broadly to encompass its learned skills.

Investments by foreign firms and their research and development (R&D) activities are increasingly motivated by prospects in the Mainland China market. It has the most mobile-phone users in the world, the largest TV market, the second-largest PC market, and a thriving Internet services industry. The high- and middle-income classes have created new demands for products and services in head-count-based industries such as telecommunications, e-commerce, and entertainment.

Recent e-commerce growth exemplifies the distinctiveness of this market. Between 2000 and 2006, Internet users in China increased at a cumulative annual growth rate of 40 percent, to a total of 123 million. Before the end of the decade, China is likely to overtake the United States on this score. A set of local dot-coms has emerged. Often cofounded by returnees to China and locals, these companies tend to adopt—although with some variations—proven business models from the United States.[3]

What is most evident is what can be called a paradigm of execution: a focus on exploiting existing knowledge. Often this is labor-intensive manufacturing with knowledge embedded in machines, tools, standard operating procedures, and product designs in industries where competition has not yet required firms to innovate or die. This produces hierarchical organizations with little variance in operations. It relies on workers who are good at carrying out orders. The rewards are usually tangible, immediate, and certain, with factor inputs going in one end of the process and products coming out the other.

In a paradigm of innovation the problem is to come up with something better (process or product). Individuals are encouraged to think outside the box and to challenge existing rules and practices. Organizations are usually less rigidly hierarchical, with enough flexibility to help vertical (including bottom-up) as well as horizontal information flows. The undertaking seems riskier and the rewards uncertain. These two concepts are shown in Table 1.

Table 1 The Paradigm of Execution versus the Paradigm of Innovation

Characteristics	Paradigm of execution	Paradigm of innovation
Attitude toward knowledge	Exploit existing knowledge as a user	Create new knowledge and own it
Attitude toward rules	Accept and execute them	Challenge, modify, and create them
Organizational structure	Structured	Structured chaos
Communication within firms	Mostly vertical (give orders, report results)	Vertical and horizontal (exchange ideas and information)
Time horizon	Focus on the present	Look further ahead
Reward	Soon, highly likely	Delayed, risky
Competition	Compete by efficiency: "Do it better"	Compete by differentiation: "Find the better thing"

Source: This table and the distinction between the two paradigms were contributed by Ming Gu, a researcher on this book.

As the table indicates, China's current stage of development is weighted toward execution, which nonetheless can lead to significant process innovations. The best example of this is the Toyota system of manufacturing, which revolutionized world manufacturing. The importance of execution has also been demonstrated by Taiwanese companies' relentless driving down of costs. In the case of Toyota, process advances eventually led to a dominant position in products, whereas Taiwanese firms' process advances are leading toward product innovations. Process innovations, too, may be occurring in some Mainland companies, but, if so, they are hard to detect because they typically do not involve patents or other external manifestations.

The flurry of start-ups in various IT sectors in Mainland China, such as those in e-commerce and IC design, began with proven ideas, business models, or technologies from the West. However, from portal to search, and auction to online community, local entrepreneurs quickly adapted these features to local markets. With several celebrated exceptions—such as FocusMedia (which produces LCD screens in elevators), Shanda (online games), and Ctrip (travel)—few have demonstrated something new.

The transition to a more innovative society presents a systemic challenge at the institutional, organizational, and individual level. Most institutions adapt slowly. The educational system may be the slowest to change, since it emphasizes learning from history, where wisdom and memorization serve as the main mechanisms for knowledge transfer. The process is widely called "stuffing the duck": facts, concepts, and formulae are known, but little attention is paid to how they can be applied and implemented.

At the organizational and individual levels, learning to innovate also involves serious and interlocking challenges. Entrepreneurial spirit abounds in Greater China, but there is a deficiency of knowledge about how to build a team capable of innovating. This reflects a widespread shortage of experienced engineers and technical managers in various IT industries. Building competent teams—let alone innovative firms—is Greater China's first and most immediate challenge.

The Challenge of Measuring Innovations

With respect to innovation in Greater China—which is defined in these pages as Mainland China, Hong Kong, and Taiwan—this book addresses four main themes. First, the quest to be more innovative is a powerful force in all parts of Greater China. It has not yet become a significant source of new technologies, nor of more than a few global companies. But several indicators show progress, particularly increasing numbers of trained people, R&D activities (including by MNCs), and patents and papers published in international journals (along with citations in both categories). The most progress so far has occurred less in products than in processes (manufacturing in Taiwan), managing logistics chains (Hong Kong), and business models (Mainland).

Second, almost all of the technologies used in Greater China originate from outside the region. Technologies and management skills are being transferred from the countries of the Organisation for Economic Co-operation and Development (OECD) and within Greater China. Several mechanisms are at work: trade in goods and services, direct investments, academic collaborations, and students going abroad—some returning not only well educated but also with valuable job skills. Many MNCs focus on design work in the IT sector. They are motivated to serve the ever-growing China market, and to develop products for global markets. In the IC industry, the most effective transfers of technology are made by MNCs that combine foreign finance with a commitment to local operations.

Third, research institutes, too, have played important roles, especially the Industrial Technology Research Institute (ITRI) in Taiwan and the Chinese Academy of Sciences (CAS). ITRI's mission is to help commerce. The CAS has many missions, but until recently, helping commerce was not prominent among them. Relative at least to the United States, such institutes produced more important research than universities.

Fourth and finally, the talent pool is enormous in Greater China, but on the Mainland it is not very experienced. Key institutions—including state-owned companies, the CAS, and universities—have not yet demonstrated world-class research abilities. Nevertheless, Chinese scholars are increasingly contributing to science and technology (S&T), as measured by numbers of papers in international journals. The quality of their research is also measurably improving, judging by citations to these papers.

In addition to these four themes, this book focuses not on making things but on introducing new things and services. The economist most famous on this topic, Joseph Schumpeter, took a broad view. He identified five types of innovations:

1. A new product or a qualitative change in an existing product
2. A process new to an industry
3. The opening of a new market
4. New sources of supply
5. A change in industrial organization

Most of these kinds of innovations are illustrated in this book. Together, along with several types of institutions, these five types define what has become known as systems of innovation. These usually exist at the national level (national innovation systems, NISs), but regional innovation systems, RISs) have also been identified, as Claudia Müller and Rolf Sternberg observe in chapter 13.

The systems concept is useful in that it provides a framework for understanding differences in the processes by which innovations are made. For instance, France has a long-established centralized system, while the U.S. system is much more decentralized. It is also interesting to consider the top-down versus the bottom-up method of allocating national resources to S&T. The Mainland has had a top-down, state-run system (which is now being altered), while Hong Kong has had a bottom-up, private system (which is also now undergoing change). One important aspect of a NIS is the connection—or the absence of a connection—among institutions. In chapter 10, Denis Fred Simon and Cong Cao, and in chapter 3, Gary Jefferson, Bangwen Cheng, Jian Su, Paul Duo Deng, Haoyuan Qin, and Zhaohui Xuan consider the case of the CAS. Before restructuring, it was largely disconnected from commerce—its great successes having occurred in the military sphere—and thus contributed little to it. ITRI, by contrast, is a very different kind of research institute, whose mission is to help industries.

Much interest in innovation focuses on R&D, and this book is no exception. R&D is an indicator of an important input to the advancement of commercial innovations. But, as this book's chapters show, formal R&D is not always necessary—many innovations have been made on the shop floor in Taiwanese companies. Another limitation is that reported R&D can encompass a range of activities, from trying to discover something new about the universe to tweaking the features of some existing product. Accepting a few (near) truths—commercial firms do not undertake basic research, for example, and universities and science institutes do not make incremental changes in products—still leaves room for a wide range of activities called "R&D."

Making progress requires defining criteria and making measurements, and here there are difficulties. It is easy to agree on big scientific/technical breakthroughs, but we would like to measure less cosmic ones by identifying and comparing novel products or services across companies within an industry and then relating them to the inputs used to make them, such as money and people. This is challenging even for narrowly defined products, and it is increasingly difficult the more heterogeneous the products under consideration. The authors of three chapters in this book undertake this task: Fuller, by estimating outputs from China's IC design sector; Jefferson and his coauthors, by estimating technology-generated revenues from China's research institutes; and Ted Tschang and Seng-Su Tsang, by estimating the market for China's new media, such as games and animation.

Measuring inputs is less difficult, although still not easy. Favorite inputs are money spent on R&D and the numbers of scientists and engineers engaged in R&D. Nor is it hard to identify possible limitations: Do tax or political considerations play a role in reported R&D? Is innovative work done in small firms adequately reported? How should new business models be considered? As Baark remarks in chapter 18: "Quantitative R&D statistics, patent statistics, and citations reflect only formal aspects of the processes of innovation. If there are few or no formal R&D expenditures, R&D statistics do not exist or, where they do exist, are of little use. Despite low levels portrayed in formal R&D statistics, there may still be extensive innovative activity taking place."

Nevertheless, reported R&D spending is a useful indicator. China's spending in this arena has been rising rapidly and promises to keep doing so. It quintupled in real terms between 1995 and 2004, doubling as a percentage of gross domestic product, GDP (from 0.6 to 1.3 percent), while the reported number of researchers increased by 77 percent. A 2005 survey of the largest R&D spenders worldwide, conducted by the United Nations Conference on Trade and Development (UNCTAD), rated China third in R&D spending globally.[4]

The Importance of Research Institutes

Intermediate outputs from the innovation process can be measured through several useful indicators. One is scientific publications. In chapter 15, Ping Zhou and Loet Leydesdorff measure the quality of such outputs by assessing both the reputation of the journals in which papers appear and the citations to them in the global literature.

From an American perspective at least, the importance of research done in institutes in Taiwan and Mainland China is striking, relative to its scale in both companies and universities. This book discusses two important research institutes, ITRI in Taiwan and the CAS in China. Baark also comments on the recent creation of institutes and science parks in Hong Kong.

ITRI is justifiably famous for its role in adapting and developing technologies for use by companies. ITRI was responsible for creating the IC foundry industry, and with its help Taiwan has become the world's most important supplier of OEM and ODM, with such products as PCs, semiconductors, mobile phones, LCDs, and more.

In chapter 2, Kristy Sha, Tzung-Pao Lin, Chih-Young Hung, and Bao-shuh Paul Lin offer a case study of how ITRI's Information and Communications Research Laboratories (ICLs) helped Taiwan to build a broadband technology equipment sector. Given that its companies were relatively weak in R&D, and that foreign firms dominated the long-distance and metropolitan city markets, the ICLs focused on broadband local loops, where it perceived a niche opportunity. As a result, Taiwan's digital subscriber line (DSL) equipment was first in the world in 2005, with 78 percent of the global market. Taiwanese vendors have advanced to the stage where they can partner with major manufacturers such as Nokia, Alcatel, and Samsung.

The Mainland's research institute structure is enormous, with about five thousand institutes nationwide, including those that function at the local level. This structure, copied from the Soviet Union, is a legacy of the planned economy. As Richard P. Suttmeier and Bing Shi put it in chapter 1, the CAS is the "backbone" of the NIS. It has enjoyed some major achievements, largely in national security, but the CAS has also had serious flaws: a decoupling from markets, a confused set of missions, and a lack of competition for research funds.

Its commercial inadequacy is captured in the observation that before reforms began in 1979, it had made forty thousand inventions but commercialized none.[5] CAS institutes retained too many nonresearch workers and scientists who had passed their peak productivity and who lagged behind international research frontiers.

Suttmeier and Shi pay special attention to the CAS reform program, known as the Knowledge Innovation Program (KIP), one of whose goals is creating thirty internationally recognized research institutes by 2010, with five of them being world leaders. Under this program, the numbers of administrative staff members have been streamlined, and more professors have been hired. The average age of scientists and managers has been reduced. Competition for funds has intensified. The number of peer-reviewed papers in *Science Citation Index* (*SCI*) journals has skyrocketed (up 148 percent between 1998 and 2004), and there has been an eighteenfold jump in patents granted. The authors report that CAS-industry relations have, correspondingly, been transformed.

The CAS is unique in having many goals. It aims, first, to be a preeminent center of basic research, performing cutting-edge, high-tech R&D; conducting research in agriculture, health, energy, the environment, and national defense; training graduates; and promoting high-tech entrepreneurship, industrial extension, and economic development in cooperation with local governments. Second, it seeks to be an honorific organization whose elite academicians play an important science advisory function.

Having so many missions raises questions. One relates to the perceived neglect of commercial innovation. Suttmeier and Shi report that many experts in China believe that commercial innovation needs to come principally from company R&D, but companies have been weak in this arena precisely because so much of this activity had been assigned to government research institutes. Managers of state-owned companies often find it easier to seek government bailouts—that is, they have soft budget constraints—than to do the hard work of carrying out R&D and introducing new technologies. In any case, more than 60 percent of China's reported national R&D is now done by industry, a large increase from the past. As the authors put it, this is not entirely compatible with a CAS-centered view of innovation, nor with the increased role now intended for university research. In short, the CAS is experiencing increased competition from the industrial sector on the one hand, and from universities on the other.

In chapter 3, Jefferson and his coauthors use three criteria to discuss outcomes from the restructuring of the research institutes: revenue generation (especially, given that most of these institutes were supposed to become self-financing), patent production, and financial return on patents. The authors find that moving institutes to S&T enterprises—the main kind of conversion—has substantially improved their research productivity. Those converted to nonprofit, nonresearch status showed some improvement, while nonprofit institutes that remained under government supervision actually declined somewhat, as measured by revenues earned from their technology.

Research and Development by Multinational Companies

In their chapter on the spread of technological competencies in *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions*, Pari Patel and Keith Pavitt offer two main reasons why MNCs tend to do their research in-house. The first is the fact that much knowledge about technology is tacit, person-embodied, and nontransferable.[6] The second is that firms are shaped by the specialties, accumulated research, and labor-force skills of their home countries. In Asia, however, where very large numbers of people are involved, the growth of skills, lower costs of telecommunications, and growing markets with distinctive demands are causing this pattern to change. Estimated R&D expenditures by U.S.-owned subsidiaries in China went from $7 million in 1994 to $650 million in 2002 and have doubtless grown since then.[7] A recent study highlights some of the perceived advantages of doing R&D in China—notably tapping the vast pool of talent and staying abreast of competitors in China and elsewhere in Asia—and predicts that these R&D labs will use China's emerging talent pools and technologies to shift their focus from support and adaptation to full-scale R&D work.[8]

David Michael, senior partner and managing director of the Beijing office of the Boston Consulting Group (BCG), offers three main reasons for foreign firms doing R&D in China.[9] First, growth in the domestic market drives companies to customize products to suit its needs, which means having more R&D capability on the ground. That China is the world's largest mobile-phone market offers a case in point. Second, Michael notes that "a critical mass of manufacturing and sourcing activity is emerging in China, and R&D is complementary to these activities . . . you need R&D to help those companies comply with your standards, to understand how they fit into your development and production processes." The third driver is talent. "There's a global war for talent," he observes, "and you can't find the talent you need in sufficient numbers just by getting it from traditional sources in the West."

Dependence on technologies from elsewhere fits the pattern for developing regions, which Taiwan and Hong Kong were until recently, and the Mainland is still. This should not be surprising, given that over 90 percent of all R&D in the world is carried out in the developed countries. Therefore, it is eminently rational for Chinese companies to acquire their technologies from abroad. They do this by following world market trends and licensing, hiring returnees with expertise, "me-too" copying, and exploiting various work-arounds, both legitimate and illegitimate. According to one Chinese venture capitalist, "Why go to the trouble to innovate when there is so much low-hanging fruit out there?"

This is not to assert that China lacks the capacity to carry out major technology projects. This capacity was evident in its nuclear weapons and space accomplishments from the 1960s on, often expressed in the phrase "two bombs and a missile." At its current state of development, however, it is not feasible for China to create technologies across a wide spectrum—and it would be wasteful to try. Nevertheless, the government finds this dependence intolerable and is determined to end it.

Many foreign firms have established R&D centers in Mainland China and Taiwan. According to official Chinese statistics, 750 foreign centers had been established by the end of 2004; most of them were set up after 2001. Eight of the world's top ten R&D–spending international companies had centers in China or India (Microsoft, Pfizer, DaimlerChrysler, General Motors, Siemens, Matsushita Electric, IBM, and Johnson & Johnson). By 2004 China had become the third most important offshore R&D location after the United States and the United Kingdom, followed by India (sixth) and Singapore (ninth). Much of foreign firms' R&D offshoring to Asia is concentrated in the electronics industry, which China dominates in the area of hardware.

What is actually going on inside the MNC centers is not easy to answer. This is because R&D activities are sensitive for competitive reasons and because foreign companies may exaggerate the technical complexity of what they are doing to gain favor with the authorities. Broadly, there is little of what is properly called "research" being done, and not a great deal of "development," but much design activity (giving a different meaning to the *D* in *R&D* from the usual one). Nonetheless, significant activities are under way.

Several chapters of this book address R&D activities by foreign companies in Greater China. Fuller's main message in chapter 4 is that foreign firms differ greatly in both the transfer and creation of technology. Based primarily on 342 interviews with government and business participants in China's IT industry from 1998 to 2006, Fuller found that a particular kind of foreign firm stands out in this respect: what he calls the "hybrid FIE." The hybrid FIE combines finances from the advanced countries with a commitment to China-based operations. Firms with foreign financing face hard budget constraints, whereas state-owned ones do not. A commitment to China-based operations implies a willingness to do serious R&D operations there, as distinct from viewing China as one place among many for such activities.

In semiconductors, Fuller reports that hybrid FIEs far outperformed others in China's technological upgrading. As the number of chip designers went from fewer than two thousand in 1998 to over seven thousand in 2003, these firms led the way in training. In interviews with firms employing about half of China's chip-design engineers, he found that hybrid FIEs trained 1,200 engineers in real design skills, whereas ordinary foreign firms trained only 100, and domestic firms at most trained 488. Furthermore, only two of the 26 hybrids were primarily doing reverse engineering, whereas 11 of the 19 domestic firms were.

In chapter 5, Lan Xue and Zheng Liang focus on foreign firms' research in Beijing. Using survey data through early 2005, the authors found low wages to be the first motivating factor, especially in software. These R&D centers have close connections within company networks, but not locally in Beijing. Although many of them have ties with universities and research institutes, Xue and Liang found these links to be weak; the centers are a kind of enclave. The authors identified both "knowledge-exploiting activities" (that is, bringing technology from outside and adapting it locally) and "knowledge-exploring" ones (creating new knowledge for global use) with the domestic market becoming increasingly important over time. However, few of these centers had applied for patents, and they were not deeply embedded in the Chinese innovation system.

In chapter 6, Yuan-chieh Chang, Chin-tay Shih, and Yi-Ling Wei distinguish between demand-oriented and supply-oriented forces in stimulating the globalization of R&D. The demand-oriented forces include integrating with production plants overseas, local ambitions among subsidiaries, host government policies, and the need for closeness to local customers. Supply-oriented forces include access to low-cost talent and access to foreign S&T. Based on interviews and a survey, the authors conclude that the R&D centers of foreign firms in Taiwan have been mainly exploiting technologies brought from overseas, but that they are gradually evolving into coordinators of regional R&D activities in Greater China and global markets. According to the authors, the main reasons that MNCs set up these centers are to support government policy and to tap local research networks. They argue that Taiwan should focus on specialized areas of S&T and emphasize the domestic market, such as in information products and services. MNCs might then want to learn from Taiwan's experience by using their R&D centers as testers of lead markets. The best examples are in mobile phones and computers. This implies a need for Taiwan to (1) have a large supply of R&D experts, strong niche research bases, and strong intellectual property (IP) protection; (2) encourage R&D–related foreign direct investment via government promotion, R&D incentives, and the creation of science parks; and (3) support stronger MNC-local R&D networks.

Wang and Wei address the links that connect Silicon Valley, Hsinchu, and Shanghai—the so-called "Silicon Triangle." Silicon Valley carries out product and technology innovation, Taiwan takes care of product development and logistics management, and China handles manufacturing. (Obviously it isn't quite this simple: companies from Europe and Japan—such as Ericsson, Alcatel, Sony, and NEC—also participate.) The authors consider the motivations and strategies of the MNCs with R&D activities in Taiwan as part of this system. Because Taiwanese manufacturers have moved their production to China it is no longer a mass-production base, and making innovations has therefore become an urgent matter. They find these centers to be highly focused on current market demand with a one- to two-year time horizon. Most are sales or regional headquarters, not R&D headquarters, and contribute little to Taiwan's technology.

Wang and Wei, in chapter 7, anticipate a tripartite future in which, first, Silicon Valley continues to focus on innovation, including creating new industries; integrating technologies; and establishing new industrial standards, marketing, and services. Second, Taiwan will become a product-design R&D center and a global supply center while sustaining its innovative low-cost model. Third, China, with low labor and land costs and market advantages, looks set to gradually become a capital- and labor-intensive manufacturing center, which will also develop its own market-oriented R&D and product designs and brands. These authors conclude that the pattern of technology division in the "Silicon Triangle" is unlikely to change much in the next five years. Taiwan's enterprises need to cooperate closely to keep their leading position globally. They need to maintain close links with U.S. companies and to bolster those connections by forging additional links to companies in Europe and Japan. Furthermore, the growing importance of services requires that Taiwan develop this sector.

Ingo Liefner and Stefan Hennemann, in chapter 8, investigate factors that determine cooperation between foreign and local firms in China, connections among high-tech firms there, and the impacts of such cooperation. Together with academic and research institute partners in China, they surveyed high-tech companies in Beijing and Shanghai, and found foreign ownership, company size, and a commitment to developing products for the China market to be the key factors. In an inquiry into public research organizations and universities, they found that the most innovative firms had close connections both with local research organizations and with foreign companies.

In chapter 9, Meng-chun Liu and Shih-horng Chen report on R&D investments by Taiwanese companies overseas. These firms began to make such investments in the late 1970s, first in Southeast Asia. In the late 1980s, investments shifted to Hong Kong's Pearl River Delta, in such industries as apparel, umbrellas, and footwear, followed by PC assembly and notebook computers. By 2005 all Taiwanese company notebook PCs were assembled in China and investment had shifted to the Yangtze River Delta region. The Taiwanese IC foundry service business began in Shanghai in 2003. Seventy percent of all Taiwanese foreign direct investment is in China, mainly in manufacturing, with the top five in 2002–2004 being electronics, basic metals, chemicals, precision machinery, and nonmetals. In contrast, Taiwanese firms' direct investments in other parts of the world are concentrated more in services. Liu and Chen's survey shows that a large majority (84 percent) of Taiwanese firms mainly use technology originated in Taiwan; only 25 percent report doing R&D locally. Those firms that do so are motivated by developing products, accessing the market, and lowering costs. Catching up with rivals' technology gets a low rating. Outside China, these firms prefer to have clients as R&D partners, but not inside. Liu and Chen highlight the general importance of MNCs having ties with local innovation networks. Promoting scientific/technological cooperation can help to foster these connections, but—they speculate—Taiwanese firms find building ties locally to be difficult.

Talent and Innovative Capacity

Anyone who doubts the depth and scale of China's talents should consider the following statement, made in chapter 10 by Simon and Cao:

> Between 1999 and 2003, Beijing University and the University of Science and Technology of China in Hefei were the two largest baccalaureate-origin institutions of U.S. doctorates in physical science (558 and 461 doctorate recipients, respectively), surpassing both the Massachusetts Institute of Technology (MIT) and the University of California–Berkeley by well over 100. In engineering, for the same period, Qinghua [Tsinghua] University was the largest baccalaureate-origin institution, with more than twice as many graduates earning U.S. doctorates than the largest U.S.-origin institution, MIT (863 versus 344).

One possible reaction to this news is that all numbers in China are big. Even so, these numbers are striking. Another response, salient to current Chinese government concerns, is that only a small proportion of these talented and well-educated people have returned to China so far.

A huge expansion is taking place in Chinese higher education, with the number of students admitted to tertiary education going from 1.5 million in 1999 to 7.5 million in 2005. The number of doctoral degrees awarded in 2000 reached 7,300, more than Japan and second only to the United States (which awarded 26,200 doctoral degrees that year).[10] Much of this expansion is in scientists and engineers; 33 percent of university students in China studied engineering, compared with 20 percent in Germany and just 4 percent in India. Official statistics for 2003 show that higher-education graduates in S&T reached 800,000—more than double the figure of a decade earlier.[11] The world has never seen such a combination of scale and speed—albeit at a cost in quality.

Vivek Wadhwa, founder and CEO of Relativity Technologies and an active member of the influential nonprofit network The Indus Entrepreneurs, raises questions about these numbers. He finds that Chinese (and Indian) official data include graduates of two- and three-year programs.[12] Particularly in China the label “engineer” is used more loosely than in the United States. Looking at all computer science and IT degrees from four-year schools in 2004, Wadhwa originally came up with a figure of 137,000 engineering graduates for the United States, compared with 112,000 for India and 351,000 for China. After further inquiry, the only clear conclusion he reached was that engineering numbers are increasing in both India and China.

For a long time, academic positions in China were relatively unattractive. The Cultural Revolution did much damage to universities, which have been slowly recovering. Although academics have traditionally been held in high esteem, pay became so low that many faculty members were forced to engage in outside business to make ends meet. This situation is improving with higher pay and more research support, but there is still a long way to go.

Cong Cao, in chapter 12, notes that the level of much of China’s scientific and technical elite is not very high from an international perspective. The members of the CAS perform many roles: doing—and managing—research, training students, providing expert opinion on a large variety of national issues, and participating in international exchanges. Their professional freedoms and their influence have fluctuated widely. From the low point of the Cultural Revolution these have risen greatly; still, few exhibit signs of political nonconformity—the Party is wary of people for whom scientific autonomy is a crucial value. Cao asserts, "It is certain that current CAS members are not at the same level as members in some of the most advanced countries." He also writes that the quality of members appointed since 1980 is inferior to those appointed earlier, a decline he attributes to the fact that more recent members were trained at home during a period in which higher education was in a sorry state.

There is also a serious shortage of experienced workers, especially in management and research, which is to be expected given the high expansion rate of graduates.[13] According to a 2005 McKinsey report, of the 1.6 million young engineers in the country, only about 160,000 have the practical and language skills necessary to work for a multinational—an amount no larger than the United Kingdom's talent pool.[14] McKinsey also reports that China will need 75,000 managers with some form of global experience in a decade; currently it has only about 5,000 such people. On-the-job experience will correct many of these deficiencies.

There is now a trickle of returnees. They have the advantage of being among the most skilled of their generation, with good education and research experience. Although their management skills are valuable, some have lost touch with changes in China, especially those who have been away a long time, and this limits their usefulness.

Simon and Cao address the demand and supply of scientific and engineering talent. Their model suggests that upward pressure in this market will be moderated over time through experience and the return of experts. They also assert that China lacks a pool of skilled people capable of breakthroughs in scientific research and technology, a perception that government officials evidently share, given their efforts to improve higher education and to recruit overseas Chinese.

Ernst asks if China will be able to move beyond being a low-cost, export-oriented global factory to becoming innovative. He sees China as having a unique combination of advantages: the world's largest pool of low-cost and trainable knowledge workers, a booming market for electronics products and services, sophisticated lead users and test-bed markets, and strong policy support for its innovation system. As a late-latecomer, China has the additional advantage of learning from the achievements and mistakes of others. Most important, China can take advantage of global knowledge networks that now extend beyond markets for goods and finance to those for technology. Ernst argues that China is more integrated into these networks than were Japan and Korea at a similar stage of their development. Corporate networks link Chinese firms to customers, investors, technology suppliers, and strategic partners through foreign direct investment, venture capital, private equity investment, and contract-based alliances. Informal global social networks connect it to overseas innovation systems through the circulation of students and researchers. He shows how integration into global knowledge networks enabled the computer company Lenovo to jump into global markets by buying IBM's PC business.

Müller and Sternberg focus on a key aspect of talent in an innovation system, and one in which the Chinese have a strong and justified reputation: entrepreneurship. They focus on Shanghai's RIS, and the role of returnees in the semiconductor and software sectors there. Through interviews, they find that returnee entrepreneurs serve an important educational function, both with workers and customers. And the activities of returnees produce knowledge spillovers that help high-tech industries in the region more broadly.

Statistical Indicators: Patents and Publications

More foreign firms are securing patents in China, and more Chinese firms are securing them abroad. China's inventors moved from fifty-seventh in the U.S. patent system in 1985 to eighteenth in 2003. Among the outsiders within China's patent system, Japanese, Taiwanese, and Korean firms are in the lead.

Fuller's research has found that the international hybrid firms, also called hybrid FIEs, stand out as a source of patents. He notes, "Examining U.S. utility patent data within the broader IT sector and in the IC sector, from 1997 through 2004, global hybrid firms (those with foreign financing and China operations) created 503 of China's 616 corporate U.S. IT utility patents. Domestic firms created only eleven and the remainder were created by foreign multinationals. Their outsized role is all the more impressive because they were competing against large-scale MNCs and growing domestic giants, such as Huawei."[15]

To discern the direction and growth of innovative activities over time in (non-Japan) Asia, in chapter 16 Poh Kam Wong traces the five hundred largest patent-owning companies in the world. He finds that the four Asian newly industrialized economies (NIEs), plus China and India, have increased their share of influential patents and also that the share of foreign patents has been growing rapidly, especially those by inventors in China, India, Taiwan, Korea, and Singapore. Taiwan has become the third-largest patenting economy in the world, behind the United States and Japan. The (non-Japanese) Asian ownership of U.S. patents granted between 2000 and 2004 varied greatly. Inventors from Taiwan received 53 percent, from Korea 32 percent, from Hong Kong 5 percent, and from both Singapore and China 3 percent. The growth rates of their patenting also ranged widely, with Singapore and China growing much faster than the others, though from lower bases. The four NIEs increased their share of influential patents worldwide and, within the top 5 percent of the most cited patents, Taiwan had overtaken the United Kingdom and closed in on Germany. Korea, meanwhile, had overtaken France and approached Switzerland.

Wong makes some observations about what he calls the "Global IP 500" companies, that is, those that own the most patents. He finds that most of these companies' patents are home-based, but that they are gradually becoming more widely distributed. Thus, the less advanced countries naturally depended on foreign knowledge when their local innovation systems were weak, but this becomes less necessary as local knowledge strengthens.

In chapter 14, Albert Guangzhou Hu focuses on China's "explosion" in patents. In 2004 outsiders accounted for two-thirds of invention patents, a higher share than in the United States and much higher than in Japan. Invention patents granted to Chinese applicants have been growing annually at almost 26 percent, but those to inventors in the United States, Japan, Germany, Taiwan, and Korea have grown even faster—with Korean ones growing at 58 percent a year.

Why is there such aggressive acquisition of IP rights when IP enforcement is so weak? Is this surge driven by foreigners' need to protect proprietary technologies against Chinese imitators, or is it spurred instead by competition among foreign investors in the Chinese market? Observing that foreign patenting in China has been growing three to five times the rate of foreign patenting in the United States, Hu infers that competition among foreign firms and between foreign and domestic Chinese firms is the driving force.

According to Zhou and Leydesdorff, the scientific production of China, as measured by publications, has grown exponentially for over a decade. Specifically, it advanced from seventeenth in the world in 1993 to fifth in 2004. China strives to be an innovative country, and the role of its scientific publications is a crucial indicator. However, sciento-metricians regard the number of citations that publications receive as more significant than publications alone, because citations show the visibility or impact of scientific output. Although higher than earlier, in 2004 China's publications ranked only fourteenth in the share of citations. Zhou and Leydesdorff ask: Why is this, and can Chinese S&T institutions make a larger contribution to knowledge?

The authors judge that too much emphasis is placed on counts of publications, which leads Chinese authors to focus on the number of publications, rather than the quality. The high share of publications and relatively low share of citations illustrate this tendency. It is not that citations are seen as unimportant in China; on the contrary, inclusion in the *SCI* is a major aim of Chinese journals' editorial boards. However, Zhou and Leydesdorff find that inclusion in the *SCI* does not necessarily increase visibility and conclude that research institutes, authors, and editorial boards need to try harder. Chinese authors, they suggest, must focus more on original and innovative research; producing papers in English particularly enhances visibility.

High-Tech Regions

Industry concentrations, or clusters, often emerge naturally. For example, national capitals attract telecommunications companies because that is where government regulators are located. Other clusters tend to form around major universities, or develop in places with nice weather or in cultural centers—or in locations that combine such factors. Silicon Valley boasts two of these three features, as does Shanghai—but not the same two. Much of Greater China's high-tech industry is geographically concentrated in such cities as Hsinchu, Shanghai, Beijing, Shenzhen, and Suzhou.

Of particular interest here is government action—sometimes successful, sometimes not—to create clusters.[16] Government created the Hsinchu Science-based Industrial Park (HSIP); Beijing and Shanghai, too, are natural sites for high-tech clusters, but governments have boosted the process. Beijing's Torch program supports fifty-three high-tech regions that are widely distributed throughout the country.

Yih-Luan Chyi and Yee-Man Lai, in chapter 17, focus on the workings of HSIP, which is probably the most successful government-created high-tech park in the world. Set up in 1980 to attract high-tech firms, including start-ups, the HSIP's goal was to become a Silicon Valley of the East. Nearby were ITRI and two major universities, National Tsing Hua University and National Chiao Tung University. By the end of 2004, HSIP had 384 tenants, and it had grown at an annual rate of 12 percent over the previous two decades. As of 2004, returnees owned almost one-third of these firms. Total sales were NT$11 trillion (US$350 billion),with an annual growth rate of 38 percent. The number of employees had increased more than ten times, from 8,275 in 1986 to 113,000 in 2004.

The success of HSIP firms is due in part to the fact that technology spills over into the knowledge networks in which they operate. This means that without paying any cost, a firm can benefit from other firms' research—that is, research performed in one firm can stimulate the creation of new knowledge or combine ideas from other firms. This type of knowledge spillover does not require direct input-output connections among firms or industries.

With patent data from HSIP and Silicon Valley firms, Chyi and Lai construct measures of knowledge spillovers, both within HSIP and between HSIP and Silicon Valley. (Their measures of international knowledge spillovers pertain to the semiconductor industry.) Hsinchu's high-tech clusters display knowledge spillovers measured by R&D performed. In particular, the authors find spillover elasticities from R&D done *outside* the companies to be higher than from the companies' *own* R&D. In the semiconductor industry they find that the foreign knowledge stock has a stronger impact on net sales than the domestic knowledge stock.

In chapter 18, Baark describes the evolution of Hong Kong's high-tech policies. Since returning to China in 1997, Hong Kong has moved away from its policy of "positive noninterventionism" and toward the fostering of technology and innovation. It has set up the Innovation and Technology Fund (ITF), supplied venture capital, and created the Cyberport, the Hong Kong Science and Technology Park, and the Applied Science and Technology Research Institute (ASTRI). Baark also notes that total R&D spending in Hong Kong, both public and private, went from less than 0.30 percent of GDP in the 1990s to (a still comparatively low) 0.69 percent in 2003. Significantly, the business sector share of R&D spending went from 18 percent in 2000 to 41 percent in

2003. Moreover, economic integration with the Mainland, the strengthening of international research linkages via its universities, the growth of overseas R&D activities by Hong Kong companies, and its role as a financial center have all created a web of innovation networks. Hong Kong endeavors to be an innovation hub for both China and global markets.

Services are especially important. Most Hong Kong firms' large-scale production facilities are located in the Pearl River Delta, and their activities at home are focused on management, marketing, and development. Services in finance, insurance, communication, and logistics now contribute more than 85 percent of the SAR's value-added. These types of firms are making innovations that are not adequately reflected in available R&D statistics. Baark mentions the famous trading company, Li and Fung, as an innovative orchestrator of loosely coupled supply chains encompassing many consumer products. It has a network of more than 7,500 suppliers. He argues that the government should enhance existing sectors rather than aim to create new innovation systems, and that an economy can innovate without focusing today on creating new knowledge. Creating new knowledge is likely to become more relevant at later stages, but policymakers should try to identify organic strengths and realize that it is possible to build on traditional strengths to attain innovative excellence.

In chapter 19, Adam Segal compares efforts to foster technological entrepreneurship in China, India, and Korea, focusing on three policy arenas: university-industry collaboration and university-related start-ups, policy support for small- and medium-sized enterprises, and venture capital. He summarizes China's current strategy as complementing its traditional state-directed top-down approach with a more bottom-up entrepreneurial method. The government now supports all domestic enterprises designated "high technology" and helps inventive entrepreneurs by doing more to define and protect property rights (including IP), using venture funds, and developing technology markets.

Segal identifies a similar desire to foster innovation throughout Asia. India is supporting small- and medium-sized enterprises, promoting university-industry linkages, and encouraging cooperation between state-run labs and multinationals. Korea's IT839 strategy—a government effort to introduce eight new IT services, encourage investment in three key network infrastructures, and develop nine promising sectors—is complemented by the promotion of venture companies and "inno-biz." These activities are taking place within NISs that do not change quickly. In China, the legacy of the Soviet system of S&T is still felt. In India, "mission-oriented" research institutes, especially those in defense and nuclear energy, cast a long shadow. In Korea, the promotion of small, tech-focused technology enterprises, university-industry collaborations, and regional ecosystems of innovation are intertwined with efforts to reduce the gap between the *chaebol* (South Korea's large, family-controlled conglomerate firms) and small firms, and between Seoul and the rest of the country.

There are important commonalities among these countries. All see opportunities in the globalization of R&D and the return of skilled expatriates.

Policymakers are learning from neighbors, entrepreneurs are cooperating across borders, and efforts to develop new standards in open software and home media are bringing firms together. The rise of China has created a wide concern that producers in all sectors will be squeezed, which adds to the impetus to promote local innovation. Segal quotes a venture capitalist in Seoul who noted that "all Koreans think about China all the time."

University-industry collaborations, too, are an active topic in China, India, and South Korea. In China such collaborations include patent licensing, technology service contracts, joint research projects, university-based science parks, consulting agreements between individual faculty members and commercial firms, and university-affiliated enterprises. In 2002, Zhongguancun Science Park, a technology hub situated primarily in Haidian District, Beijing, was home to more than 9,500 high-tech firms, more than 200 of them university-affiliated. In 2007 that total reached 20,000 firms. There are, however, certain negatives in blurring the lines between industry and academia, most notably the impact of commercial activities on the academic environment.

Indian universities have received proportionately less research funding than their Chinese counterparts and have been less closely linked to companies. Neither faculty nor companies have valued the connection, with many academics preferring to connect to MNCs than to local firms.

Korean universities have faced similar barriers. Often weak in research, they have faced legal and social barriers to entrepreneurship. Although these barriers are being reduced, the overarching question of the proper balance of education, university research, and commerce remains.

Segal sees some convergence in policies toward small firms across these countries, as well as similar barriers: ineffective policies, a dearth of early-stage capital, a lack of scale, weak technological capabilities and management skills in small firms, and cultural barriers to entrepreneurship. He suggests that the shift toward an innovation strategy has not gone far enough because it still posits a central role for government. Instead, he sees success depending more on the roles of civic and business associations. In India it is the growing number of successful entrepreneurs involved in business-plan competitions, entrepreneurial clubs at the Indian Institutes of Technology (IITs), and angel capitalists who will overcome cultural barriers to networking and risk-taking. Only through more active and independent involvement of such groups will entrepreneurship be fostered.

Intellectual Property: The Cases of Chips and the New Media

In addressing IP protection in China, Xiaohong Quan, Henry Chesbrough, and Jihong Wu Sanderson observe in chapter 20 that there is no lack of statutes and that case law is forming in trademarks, copyrights, and patents. Enforcement, they note, is the problem. However, the government is coming to understand that creating IP requires protecting it.

In the IC sector, the authors assert that government efforts (in money, equipment, talents, and so forth) to make a competitive manufacturing industry have failed, while design houses, with no government effort, have flourished. In 2005 there were around six hundred design houses, of which a few that are run by returnees, such as Vimicro and Spreadtrum, had global competence.

Given that IP protection is weak, Quan and her coauthors ask why there are so few infringements in this industry. Or, if there are infringements, why is this not a big concern for designers? They argue that the growing complexity of semiconductor designs makes imitation very difficult and that even successful infringers would have trouble selling their products to foundries or system companies. In any case, patents are effective in only a few industries, such as the chemical one. In other industries, lead time, learning curve advantage, secrecy, and sales and service efforts offer better means of appropriating IP.

Quan and her coauthors mention several ways in which IP is being protected. Different actors specialize in different activities along the supply chain; such specialization can be done within a company across levels and locations. For example, one MNC the authors studied carefully separated its systems-design work from specific components—the systems work is done at home, while parts of the implementation are done in the firm's China laboratory. Another firm refused to move people across processes, so that any employee leaving the company would at most know a single process.

Tschang and Tsang address the new Chinese media in chapter 21. This market has seen intense, imitative, cost-competitive competition, which makes it hard for firms to differentiate themselves on IP and other output characteristics. Foreign producers have occupied strong niches or held dominant market shares. Tschang and Tsang focus in particular on animation, video games, and mobile-phone content. In contrast to manufacturing and much software, this is a domestic market with distinctive preferences—as, for example, in animation—in which government regulators play large roles. With advanced mobile phones, the rapidly growing sales of mobile-phone games was predicted to be $3.8 billion in 2007, making it the fastest-growing market in the world. Tschang and Tsang see big challenges for suppliers, especially in anticipating consumer demands and cultivating hits in a market where tastes vary across provinces. There is also a huge shortage of marketing and other talent that may last for years.

Online games naturally have much lower piracy rates than packaged traditional games (which have a piracy rate as high as 95 percent), but because users want multiplayer games, broadband penetration is critical. Broadband connectivity in homes might stimulate multiplayer online games in the same way advanced handsets did for mobile-phone games. In 2003, 70 percent of the online games in China were made in Korea, a troubling fact that led the government to restrict foreign games. Domination (to the tune of 90 percent) of the animation market by producers from Japan, the United States, and South Korea also led the government to adopt protectionist measures in this sector.

One consequence of protecting these industries on cultural grounds is that the government has gotten serious about IP protection for domestic content. More broadly, government policies include funding (for programs and infrastructure), protection (such as bans on foreign content and reservations of space in the various channels for domestic content), training, and various forms of promotion. The decision to spend $1.8 billion to develop one hundred online games based on Chinese history and heroes means trying to pick commercial winners, an activity that governments do poorly, and one—as Tschang and Tsang observe—that is especially dubious given how hard it is to anticipate consumer demand.

Intense price competition suggests the importance of ideas for new gameplay and technology. Countries with deep traditions in creative work foster new kinds of games and gameplay. Tschang and Tsang note that this bears on the possible social consequences of government prohibitions on foreign content. While limiting influences from global entertainment might be deemed "good," such bans might deny players exposure to a variety of influences, including potentially new sources of innovation. China risks raising a generation of players not exposed to new gameplay styles.

Given the intense domestic and foreign competition in online games, it may be difficult for all but the largest Chinese firms to compete, at least in the near term. This is similar to the software industry's experience, where domestic firms were unable to match foreign multinationals at the high end of the market and were competing destructively with one another at the low end.

Looking Ahead

China's leaders find dependence on foreign technology deeply unsatisfactory. They consider it to be unseemly for a great nation. There also exists a perceived national security vulnerability, and there is resentment at having to pay royalties to foreigners. The government aims to change this pattern by turning China into a major creator of S&T. The announced goal is "self-reliance," meaning reduced use of imported technology or, more broadly, IP. The 15-Year Science and Technology Plan specifies sixteen major engineering projects, including design of large aircraft, moon exploration, and drug development. The plan further highlights four major basic research programs: protein science, quantum physics, nanotechnology, and developmental and reproductive science. Each of these four programs is to receive about $1 billion. The plan places the National Center for Nanoscience and Technology and the Beijing Protein Research Center in charge of the megaprojects in their fields.

One issue is a top-down versus bottom-up decision process for these programs. That a mix of the two methods is appropriate should not be in doubt, but, for China, a balance requires a more decentralized process than it has historically embraced. Many scientists perceive this need; for example, those in developmental and reproductive biology say they intend to establish a merit-based system to distribute funds.

R&D spending by all sources, industry included, is supposed to go from $30 billion in 2005 to $113 billion in 2020. Basic research is to climb from 6 percent of R&D expenditures in 2004 to perhaps 15 percent in fifteen years. The goal is to make China a world powerhouse of S&T.

There are challenges to achieving this goal, several of which this book addresses. However, there should be little doubt that with the talents and resources available, China will reach its objective. The growth in the numbers of better-educated young people is extraordinary, as is the government's commitment to creating technology. China will become a major source of technology, but there are questions about its path over time.

Notes

[1] See National Science Foundation (NSF), *Science and Engineering Indicators 2006*, vol. 2 (Arlington, VA: NSF, 2006), Tables 6-1 to 6-4.

[2] See Greg Linden, Kenneth L. Kraemer, and Jason Dedrick, "Who Captures Value in a Global Innovation System? The Case of Apple's iPod," Personal Computing Industry Center (PCIC), University of California, Irvine, June 2007.

[3] See John Hagel III, and J. S. Brown, *The Only Sustainable Edge: Why Business Strategy Depends on Productive Friction and Dynamic Specialization* (Cambridge, MA: Harvard Business School Press, 2005).

[4] See United Nations Conference on Trade and Development (UNCTAD), *World Investment Report 2005* (New York: United Nations, 2005), 20. But Bergsten et al. criticize this report's purchasing power parity (PPP) adjustments to R&D spending, calling them "dubious" and almost certainly leading "to substantial overstatement"—see C. Fred Bergsten, Bates Gill, Nicholas R. Lardy, and Derek Mitchel, *China: The Balance Sheet: What the World Needs to Know about the Emerging Superpower* (New York: Public Affairs, 2006), 174.

[5] After the reforms began, however, the CAS spun off Legend Computer, now Lenovo.

[6] Pari Patel and Keith Pavitt, "The Wide (and Increasing) Spread of Technological Competencies in the World's Largest Firms: A Challenge to Conventional Wisdom," in *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions*, ed. Alfred D. Chandler, Peter Hagstrom, and Orjan Solvell (New York: Oxford University Press, 1999), 192–213.

[7] NSF, *Science and Engineering Indicators 2006*. vol. 2.

[8] UNCTAD, *World Investment Report 2005*, 26.

[9] Boston Consulting Group (BCG), "The New Global Challengers: How 100 Top Companies from Rapidly Developing Economies Are Changing the World," report, May 2006.

[10] Andrew Wyckoff and Martin Schaaper, "The Changing Dynamics of the Global Market for the Highly Skilled," Organisation for Economic Co-operation and Development (OECD), "Advancing Knowledge and the

Knowledge-Economy" conference, National Academy of Science, Washington, D.C., January 10–11, 2005.

[11] National Statistics Bureau, China, 2004.

[12] Vivek Wadhwa, Testimony to the U.S. House of Representatives Committee on Education and the Workforce, May 16, 2006.

[13] Heidrick & Struggles and the Stanford Program on Regions of Innovation and Entrepreneurship, "Getting Results in China: How China's Tech Executives Are Molding a New Generation of Leaders," special report, 2006.

[14] *The McKinsey Quarterly*, November 2005.

[15] Douglas Fuller, "China's Global Hybrid Model: A New Path to Development Under Globalization," manuscript, 2006.

[16] For an examination of failed efforts to create high-tech clusters, see Scott Wallsten's "High-tech Cluster Bombs: Why Successful Biotech Hubs Are the Exception, Not the Rule," AEI-Brookings Joint Center, March 2004.