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CHINA, SEMICONDUCTORS, AND SECURITY

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CHINA, SEMICONDUCTORS, AND SECURITY

WILLIAM W. KELLER AND LOUIS W. PAULY*

Introduction

Theoretical and Political Context

China's rise is topic number two these days, in both international relations and foreign policy circles. Many predict it will soon be number one, and that it will remain so for a long time. This paper focuses on one aspect of that topic, the establishment and expansion of the industry currently viewed by China's leaders as a key strategic priority: the industry that makes semiconductors, the microchips at the core of computers, electronics, telecommunications, weapons systems, and much more.¹ More specifically, it

* Paper prepared for the Working Paper Series of the Research Group in International Security (REGIS), Université de Montréal and McGill University. All rights retained by the authors.

¹ This paper is based directly on a collaborative research project, "Applied Research in the East Asian Semiconductor Industry," currently underway. We are grateful for the support of the Ridgway Center for International Security Studies at the University of Pittsburgh, the Center for International Studies at the University of Toronto, the Canada Research Chair Program, and the Semiconductor Research Corporation. Fieldwork was undertaken in the spring and summer of 2004 in Washington, Silicon Valley, Hong Kong, Beijing, Shanghai, and Xi'an. Special thanks to the Faculties of Engineering at City University in Hong Kong, Tsinghua University in Beijing, and

concentrates on the present and likely future expansion of the base for applied research in this sector.² The building of such a base is a crucial step in the value-added innovation-production chain. In its absence, only low level assembly operations are possible; in its presence, high-level innovation and the kinds of basic research required for future system-transforming, system-leading breakthroughs may begin to develop.

Since this is a workshop on international security, the concept of balance-of-power seems the obvious place to start thinking about the theoretical and policy implications of the empirical evidence summarized in this paper. As Mark Brawley has recently put it, "The prime candidate for balancing the United States today or in the medium term is China."³ Despite its lack of obvious allies, do China's economic and security policies suggest that China is clearly moving in such a direction? China's leaders would have to be crazy to be unsubtle about this, and, in any event, the Chinese political economy is far too complex to admit of unambiguous policy

¹ Fudan University in Shanghai. Logistical support and advice was provided by the Semiconductor Industry Association, the MIT International Science and Technology Initiatives, the North American Chinese Semiconductor Association, and the United States Information Technology Organization in Beijing. Noman Lateef and Adam Bowers provided research assistance.

² This study follows earlier work on Japan, Taiwan, and South Korea. See William W. Keller and Louis W. Pauly, "Crisis and Adaptation in Taiwan and Korea: The Political Economy of Semiconductors," in *Crisis and Innovation in Asian Technology*, edited by William W. Keller and Richard J. Samuels, Cambridge: Cambridge University Press, 2003, pp. 137-159; and "Crisis and Adaptation in East Asian Innovation Systems: The Case of the Semiconductor Industry in Taiwan and South Korea," *Business and Politics*, vol. 2, no. 3, November 2000, pp. 327-352.

In the latter two country cases, we documented both the rapidly developing success of university systems in training engineers and the ability of local industry to absorb and conduct high-quality applied research. On the Japanese case in closely related industries, see Paul N. Doremus, William W. Keller, Louis W. Pauly, and Simon Reich, *The Myth of the Global Corporation*, Princeton: Princeton University Press, 1998.

³ Mark R. Brawley, "The Political Economy of Balance of Power Theory," in *Balance of Power: Theory and Practice in the 21st Century*, edited by T.V. Paul, Jim Wirtz, and Michel Fortmann, Stanford University Press, 2004, p. 94.

directions. In such a context, "The rational choice for China would be to appease the United States while continuing to build up its economic resources."⁴ The trouble for analysts seeking empirical evidence in this regard is that this leaves interpretation completely open. As long as US-China relations remain on a reasonably even keel, any evidence of the building up of internal strategic resources in China can be interpreted either as evidence of a long-run strategy of balancing or of a long-run strategy of deep transformation and peaceful integration. In the language of the current debate being waged in practically every issue of the journal *International Security*, such an analytical framework cannot answer the question of whether China is becoming a 'status quo power.' It cannot do so because it cannot separate capabilities from intentions, and it cannot make any less thorny the intersubjective character of those intentions. In other words, I agree with Brawley that balance-of-power theory is too parsimonious, is ill-equipped to deal with the mutually constructed intentionality of policymakers, and too unsubtle for policy prescriptions.

But the question of the character of China's emerging power remains vitally important, and direct policy implications of our explicit or implicit answers are all around us. Should residual post-Tiananmen Square export controls finally be dropped? Should Chinese state-owned enterprises be restricted in any special way when they seek to buy firms owning Canadian natural resources? Should the enforcement of intellectual property rights rules in China be left to the weak compliance structures embedded in the WTO? Should the G-8 be opened up permanently to include China? Should Chinese oil interests be permitted to trump imperatives for humanitarian interventions in east Africa? How should our own broadly-defined industrial policies be adjusted to compete with parallel policies in China? Should the US and Canada pursue

⁴ Ibid.

policies that accelerate China's industrial competitiveness? These are all practical and immediate questions facing us.

Can IR scholars shed any light? Probably not, if we hold too tightly to analytical frames that admit of entirely contradictory interpretations of the same evidence. Probably so, if we open ourselves to comparative analysis rooted in history, if we subject our findings to continuous debate, and if we listen with only one ear to historians and China experts reluctant to draw conclusions. In approaching big strategic questions this way, however, it is also wise freely to admit that the best we can do is to make a case for the marginally more plausible interpretation of evidence over the marginally less plausible. Humility, in other words, is essential.

Why Study the Semiconductor Industry in China?

China's rise is transforming the regional and global foundations of the semiconductor industry. Biotechnology may be the key industry of the future, but micro-electronics is arguably the key industry of the present. Certainly Chinese industrial planners see it this way, for they have assigned it their leading strategic designation. The development within China not only of a competitive manufacturing base for integrated circuits (ICs), but eventually also of a serious national system for related research and development poses new challenges for the industry globally. The evolution of an *applied research base*, coming out of and directly tied to now-burgeoning manufacturing operations, is an essential early step. This study provides an assessment of that evolution and of the factors likely to propel it and impede it in the years ahead.

The most important factor underlying the development of China's applied research base in semiconductors is the expansion of a vast and unprecedented pool of engineering and scientific talent throughout that country. Internally generated talent and skills are

currently being augmented by the migration to China of highly educated engineers, many of Chinese origin and returning with industry experience, mainly from the United States and Taiwan. Expertise is now flooding into China, both as Chinese firms expand their recruiting abroad, and as large-scale foreign direct investment bolsters a semiconductor industry expanding to serve global and, increasingly, internal markets. An internationally competitive semiconductor manufacturing industry in China will fully establish itself in the near term; in the medium term, despite impediments all too obvious within China today, this will likely soon be followed by a competitive applied research base. Before we examine suggestive evidence in this regard, some contextual notes may be helpful.

Technology and China's Rise

There are forces there [in China] which neither you nor I understand, but at least I know that they are almost incomprehensible to us Westerners. Do not let so-called facts or figures lead you to believe that any Western civilization's action can ever affect the people of China very deeply.⁵

— Franklin D. Roosevelt

History never actually repeats itself, and some seven decades after President Roosevelt delivered this opinion, it is surely true that Western understanding of China has improved. Nevertheless, there are striking parallels between the situation for business, especially foreign business, in contemporary China and the situation in the early decades of the twentieth century. The earlier story is also characterized by market opening, political liberalization, and economic transformation, and Barbara Tuchman famously chronicled its American side.

⁵ President Franklin D. Roosevelt, in a letter to a friend, 1935. Quoted in Barbara Tuchman, *Stilwell and the American Experience in China, 1911-1945*, New York: Macmillan, 1970, p. 249.

Foreign enterprise, Tuchman pointed out, "dragged China into the twentieth century, developing her economy, awakening political consciousness and breaking down her seclusion."⁶ The need to throw off sclerotic tradition and adapt to modernity came home to Chinese officialdom in the wake of Japan's shocking victory over Russia in 1905. Self-strengtheners, or as we would call them today—techno-nationalists, began pushing the Chinese state to follow Japan's example. A powerful impetus to upgrade China's human capital as well as its technology base had recently been given by the United States Exclusion Act of 1904. The Act ordained specific and permanent exclusion of Chinese workers, the result of heated agitation against 'coolie labor' imported to lay the transcontinental railroads. Resentment in China was fierce, and a boycott of American goods in 1905 spread to twenty-five cities right through the coastal provinces. Western ideas, however, were exempt because few saw any serious alternative to Westernization. And then, as today, many of those ideas entered China embedded in the brains of returning students. As Tuchman noted, "The returned students from the United States and Europe, with their degrees in engineering or agriculture or political science, their Western clothes and eyeglasses and earnest look, formed a new class as distinct in spirit from the silk-gowned mandarin with the button of rank on his skullcap and long mustache hanging down to his chest as they were in appearance."⁷

Despite reaction to the Exclusion Act, American business—and missionaries—saw phenomenal opportunities on the horizon. Secretary of State John Hay said that whoever understood China held the key to the world's politics for the next five centuries. President Theodore Roosevelt went further: "Our future history will be more determined by our position on the Pacific facing

⁶ Ibid., p. 33.

⁷ Ibid., 34.

China than by our position on the Atlantic facing Europe."⁸

That may or may not turn out to be the case soon, but the first chapter in the history of U.S.-China economic relations ended in civil war, revolution, closure, and authoritarian repression. Even nascent Chinese liberals had come to resent foreign dependence that resulted from the first opening, especially dependence on loans that often ultimately entailed ceding control over Chinese industries and markets. In the absence of war with Japan, things may well have turned out differently. But by 1949, the fundamental reality was clear. "China went her own way as if the Americans had never come."⁹

When Deng Xiaoping reopened the book on China's modernization in 1978, echoes of the past were unmistakable. Western technology, embedded in both tools and minds, was critical. Dependence on foreign loans would be minimized. Direct foreign investments would be conditioned on tangible technology transfers, and foreign majority control of Chinese enterprises would be carefully limited. A new resource, however, would be tapped to the fullest extent possible. Chinese business networks flourished in the diasporas that followed the first failed attempt to leap quickly into modernity. Their nodes spread from Hong Kong and Taiwan to southeast Asia, Europe, and the United States. Re-linking old China directly into them had both a supply-push and demand-pull logic. In this light, it hardly appears surprising that overseas Chinese networks and foreign joint venture partners would form the key building blocks for success in the top priority sectors for industrial development in the new opening: semiconductors and information technology.

China possessed hardly any integrated circuit industry at the

⁸ Ibid., In 1908, Roosevelt remitted America's share of the Boxer indemnity, the unpaid portion to be allocated for the education of Chinese students in the United States. Among other things, this helped provide an endowment for Tsinghua University, an institution now aspiring to be the MIT of Beijing. A plaque commemorating the gift is at the door of the Faculty Club.

⁹ Ibid., p. 531.

time of Deng's policy reform. By 1985, it had imported some two dozen 3-inch wafer semiconductor lines, the first from Japan's Toshiba in 1982. Ten years later, Huajing Electronics, the pioneering state-owned enterprise in this sector, followed this up with 5-inch manufacturing-on-silicon (MOS) lines from Siemens and Lucent. In 1998, Huajing bought a 6-inch line from Lucent. With technology and joint-venture capital from Motorola, NEC, STMicroelectronics, Mitsubishi, Philips, Siemens, and Toshiba, five other Chinese firms—Huawei, Shanghai Belling, Advanced Semiconductor Manufacturing Corporation, Shougang, and Huahong—did the same.¹⁰ Given the recent pace of change in this dynamic and still-highest priority sector, these relatively recent innovations seem like ancient history.

By 2005, the domestic Chinese market for semiconductors—the fastest growing in the world—is expected to exceed \$25 billion. On current trend, that market will be the second largest after the United States. With ninety-five percent of electronics production still dependent on imported chips, however, the government remains committed to ambitious goals for domestic substitution. The Industry Ministry's Ninth Five-Year Plan targeted large-scale indigenous chip production on 6-inch wafers using an 800 nanometer (nm) design rule. Eight-inch wafers with design rules as low as 300nm and advanced packaging technology were targeted for prototyping under the Ministry's Project 909. In 2000, Huahong-NEC was producing 350nm chips on 8-inch wafers and was exporting 10,000 wafers (primarily memory chips) per month to Japan. China's new semiconductor era had begun. (In 2004, the world's leading semiconductor manufacturers were capable of operating at a design rule below 100 nm.)

¹⁰ Weifeng Liu, Michael Pecht, and Zhenya Huang, "China's Semiconductor Industry," in Michael Pecht and Y.C. Chan, eds. *China's Electronics Industries*, College Park, MD: CALCE EPSC Press, 2004, p. 79.

The Tenth Five-Year Plan commencing that year specified a production goal of 20 billion integrated circuits (ICs) per year, and an import substitution goal of 30 percent of local demand and 50 percent by 2010. It envisaged up to four new 6-inch production lines, five 8-inch 350-180nm lines, and two 12-inch 180-130nm lines. It also targeted an array of national R&D centers focusing on high volume production technology and system-level ICs, as well as a sufficient number of IC design and computer-assisted design (CAD) companies to generate annual revenues exceeding \$10 million. Finally, it promised significant assistance for selected Chinese packaging, testing, equipment, and materials companies.¹¹ More directly, restrictions were reinforced on foreign investors and vendors. Although the desire for rapid technology transfer and the simultaneous acceptance of WTO obligations suggested some eventual loosening of those restrictions—especially those specifying less than 51 percent foreign control of joint ventures—it remained clear that industrial planners kept an eye trained on the country's historical experience.

Rapid economic development in China continues to depend on technology transfer from abroad, as it did in the early twentieth century. But this time a basic commitment to national control in strategic industrial sectors seems firm, and semiconductors is certainly one of those sectors. The delicate task of accelerating the inward transfer of technology without recapitulating the historical experience of excessive dependence on foreigners lies at the core of a novel political experiment. That experiment combines capitalism with centralized national planning and decentralized local governance. It also poses stark challenges for an industry that well exemplifies both the conflictual and the cooperative faces of globalizing capitalism.

¹¹ Ibid.t

Evidence and Analysis

Background

A range of policy debates, in the world's major semiconductor manufacturing firms, in universities, and in governments, now swirl around early evidence of China's rise in this sector. The question of when China's base for applied semiconductor research will reach internationally competitive levels is important, but virtually all close observers expect this development to be inevitable. The more important question has to do with the character of that base when it does mature. Will it remain a net taker of technology from world markets, or will it become a more open and steady contributor?

From its earliest days, China's integrated circuit industry aimed at self-reliance. Korean and Japanese integrated device manufacturers were attractive models for firms like Huajing and Shanghai Belling. By 2000, however, the foundry model pioneered by Taiwan had clearly become the dominant one, even if individual device makers (IDMs) could remain a strategic objective for the long term. Burgeoning demand for semiconductors, both locally and for export, was a significant reason for the switch in preferences. Even low-end Chinese chips simply could not be produced fast enough. The promise of relatively quick profits, based on a low-cost manufacturing strategy, was also at work, and this certainly helped attract foreign foundries. Report 1997.

Table A:
Total IC Demand and Production in China (billion units)

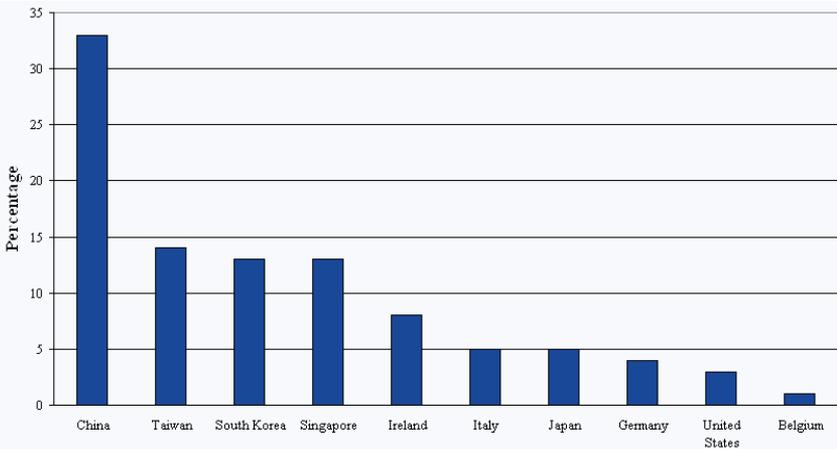
Year	Total IC Demand ¹	China's Total IC Output ²	IC Demand Met from
			Domestic Production (%)
2000	24.1	5.4	22
2001	22.0	4.9	22
2002	26.9	8.0	30
2003	33.0	10.4	32
2004 (forecast)	41.2	14.0	34
2005 (forecast)	49.5	20.0	40
2006 (forecast)	100.0	50.0	50

1. SEMI_ estimates, Weng 1996 and CEInet China IT Market Report 1997.
2. China Electronics Industry Yearbook 1997.
3. CEInet China IT Market Report 1997.
4. Duo Wei News 2000c. Chinese Electronics Industry Year Book, 2001.
5. China's Electronic Industry Outlook 2002

Source: Michael Pecht and Y.C. Chan, *China's Electronics Industry* (College Park, MD: CALCE EPSC Press, 2004), p. 82

But more subtle factors were just as important. Business networks established after 1949 by overseas Chinese clearly sought opportunities to establish critical nodes back in China. Taiwan's foundries—and the entrepreneurs with experience inside them—are the best example; their role in helping to build China's newest semiconductor fabrication facilities (fabs) is obvious. As Figure A indicates, of the all fabs being built around the world last year, 33 percent were in China and 14 percent in Taiwan. Such developments have been welcomed, and even endorsed by official

Figure A
Percent of Worldwide Fabs Under Construction By Country of Location



Michael Pecht and Y.C. Chan, *China's Electronics Industry* (College Park, MD: CALCE EPSC Press, 2004), p. 85

and unofficial patronage—and for many reasons.

Foundries promise economic growth and an expanding array of skilled jobs for local and provincial governments. They also promise wealth for local and national elites who invest in them. Over the next ten years, massive growth is forecast for China's computer components market; in 2002, the Semiconductor Manufacturing International Corporation (SMIC) forecast a 21 percent compound annual growth rate.¹² In addition, China is already the world's largest market for mobile phones, and on its way to be the largest market for other consumer electronic products. Import substitution alone would justify the foundry strategy, even in the absence of financial incentives provided by various levels of government. (The contention that the manufac-

¹² *China's Electronics Industry 2004*, p. 84.

¹³ For a fine and thorough treatment of this issue, still highly relevant even after China has agreed to remove the VAT rebate system, see Dewey Ballantine LLP, *China's Emerging Semiconductor Industry: The Impact of China's Preferential Value-Added Tax on Current Investment Trends*, Washington, DC, October 2003.

ture of advanced chips in China is purely a function of VAT rebates and other trade-distorting measures is open to serious doubt.¹³⁾

In addition to obvious strategic factors pulling local and foreign investment into Chinese foundries, the most important long-run implication may be that the foundries have opened a critical avenue for the import of leading-edge manufacturing technology. This is exactly what is required to implement the stated intention of national leaders to ‘catch up’ with the West and even to ‘leapfrog’ into next-generation electronics.

Semiconductors and Talent Migration

China is now drawing heavily upon an intellectual reserve built up over the past 20 years in the Chinese diaspora. U.S. National Science Foundation data indicates that 50 percent of all science and engineering (S&E) doctorates awarded to foreign students in the United States are accounted for by Chinese, Taiwanese, South Korean and Indian citizens (68,500 of 138,000). Chinese students comprise the largest group: engineering and biology are the two largest fields.¹⁴

Since 1985, approximately 70 percent of Chinese citizens who earned their S&E doctorates from U.S. universities stayed in the United States for employment in post-doctoral programs.¹⁵ If the pattern for Taiwanese who earned S&E doctorates from U.S. universities holds, this will soon begin to fall. During the 1990s, these highly educated Taiwanese were lured home by a variety of enticements now commonly offered by semiconductor companies operating out of Beijing and Shanghai. Certainly official Chinese government programs have been designed to reduce this ‘brain drain.’ Anecdotal evidence suggests strongly that burgeoning new opportunities in Chinese electronics and other industries are begin-

¹⁴ National Science Board, *Science and Engineering Indicators 2004*, Table 2-9, p. 2-31.

¹⁵ National Science Board, *Science and Engineering Indicators 2004*, p. 2-33.

ning to work in the same direction. At the same time, as will be described and analyzed below, such efforts are complemented by a national commitment to expanding rapidly, in both absolute and comparative terms, the size of the national talent pool in the sciences and, especially, engineering.

The Development of Manufacturing Technologies

It is well known that the success of the foundry model in Taiwan depends on a highly trained workforce. As important, however, has been the ability of chip manufacturers to convince their customers that intellectual property is sacrosanct. Given the recent troubled history of Chinese intellectual property protection regimes, this remains problematic even as World Trade Organization (WTO) disciplines kick in. Nevertheless, internally generated competitive pressures among foreign chip producers—who worry about gaining a position in future Chinese electronics markets—push in the opposite direction. Here is where current U.S. policy debates about offshoring, and especially about Chinese strategic intentionality, gain relevancy.

A 2002 GAO study found that after ten years of explosive growth, China was only two generations behind in semiconductor manufacturing technology, and one generation behind "the commercial state-of-the-art."¹⁶ This is somewhat exaggerated, since it gives too much weight to innovations in the most advanced foundries, which are unlikely in the near term to outclass well-established foundries in Taiwan and elsewhere. China's foundries remain focused even for lower-end chips on export markets. Nevertheless, it is becoming increasingly clear that leading-edge Chinese foundries intend to compete directly with the best in the world. They also intend eventually to focus more of their sales efforts on internal Chinese markets.

16 GAO 02-620, cited on page 109 of Walsh/Stimson Study.

Security Complications and Export Controls

The near-term prospects for open, mutual collaboration are complicated, however, by signals on the national security front emanating from China's central government and from the PLA. Even though Jiang Zemin finally abdicated formal political control over the military, policies he championed to compensate for China's conventional military weakness by encouraging the rapid import and absorption of microelectronics technology are likely to persist. Certainly the PLA would like to leapfrog to next-generation innovations and enhance asymmetric warfare capabilities. Few western military observers would bet on success in this regard, but the rhetoric of China's leaders is being taken seriously in defense policy circles in the United States and in Congress.¹⁷ For their part, senior Pentagon officials assert that the PLA is already supported by a 'cutting-edge' domestic semiconductor industry focused on 'pockets of excellence.' The claim is that sophisticated chips are already being produced to fit military requirements for long-range precision strike capabilities, information dominance, command and control, and integrated air defense. Pockets now being developed are said to include advanced phased-array radar, anti-satellite technology, and electromagnetic pulse weapons.¹⁸ At the same time, expert observers are aware that the hierarchical structure and risk aversion of China's military industry continue to make it difficult for the PLA to integrate sophisticated weapons systems effectively.¹⁹ Acquiring the tools to innovate is also a serious challenge.

Export controls designed to slow the pace of semiconductor tool acquisition and/or development are fraught with complexities. The loose Wassenaar Arrangement on Export Controls for

¹⁷ See U.S.-China Economic and Security Review Commission on China, *2004 Report to Congress*, Washington, DC, June 2004.

¹⁸ Michael Pillsbury, "China's Military Strategy Toward the U.S.: A View From Open Sources," background Paper prepared for the U.S.-China Economic and Security Review Commission on China, *2004 Report to Congress*.

¹⁹ GAO-02-620, pp. 16-17.

Conventional Weapons and Dual-Use Goods and Technologies confronts the reality that only the United States considers problematic the acquisition of semiconductor manufacturing equipment by China. In 2002, the GAO found that under competitive pressure, European, Japanese, and even U.S. authorities were licensing the sale of tools at least two generations more advanced than specified Wassenaar thresholds.²⁰

From the point of view of foreign semiconductor firms operating in China, the concerns of the U.S. military tend to be overwhelmed by now-obvious opportunities and competitive forces. If there is a long-term threat on their horizon as they see it, it is a threat to future profitability, given the possible future development of a more autonomous and less open semiconductor industry emerging in China across the whole value-chain. But such a threat is ultimately a function of local design capabilities.

Innovation in the Chinese Semiconductor Industry

Despite early efforts by government at various levels to stimulate design centers, design industry revenues in China do not yet exceed \$250 million per year. Most indigenous chips are application-specific (ASIC) or customized for relatively inexpensive and easy to produce local power-management products. Few Chinese designers at this stage are able to work on sophisticated system-on-a-chip designs. Until 1995, there was little capability in either the design or test areas outside of Fudan, Tsinghua, and Peking universities.²¹

By 1999, however, the state-owned IC Design Center in Beijing had produced an 8-bit CPU for smart cards (using 800nm tech-

²⁰ Ibid., p. 17-18. Competitive pressures have increased ever since a famous case in 1998, where Emcore of the USA was denied permission to sell an advanced metal organic vapor deposition machine to Hebei Semiconductor Research Institute. The German tool maker, Aixtron GmbH immediately scooped up the contract and supplied a comparable machine. Strong diplomatic protests in this and subsequent cases have accomplished little.

²¹ *China's Electronics Industry 2004*, p. 85, and interviews.

nology) and an MP3 decoder, with China's first complete large-scale CAD system. The Center is now reported to be capable of prototype and even production testing on a small scale, and is also reported to be sharing its expertise with more recently established design centers in seven locations around the country. A similar pattern is observable in the National Engineering Center for ASIC Design, which grew out of the Microelectronics Institute of the Chinese Academy of Sciences, which concentrates on IC analysis tools. Fabless design houses are also springing up, and by 2003, 150 companies employing 3000 engineers were reliably estimated to exist. Most were located in government sponsored centers in Shanghai, Beijing, Shenzhen, Wuxi, Chengdu, and Xi'an. But frankly, less than half a dozen accounted for 50 percent of the national market.²²

Interviews—as well as personal observation at showcase design centers in Beijing, Shanghai, and Xi'an—suggested that the industry is off to a modest start. It is important to note, however, that its future potential is already sufficient to have generated keen interest from global semiconductor tool manufacturers. EDA vendors and foreign and local foundries are active. Among others, Huawei in Shenzhen has reportedly developed a variety of relatively advanced tools.²³ And universities other than the Big Three have demonstrated the existence a serious new market for EDA tool makers.

As has been the case in other countries, there is in China an evolutionary movement in the indigenization of semiconductor production. Reverse engineering and process emulation lead to learning and gradual innovation. A generation ago, Japan was not expected to be in a position to support a high-level industry, and especially not an advanced tool industry. Expectations changed swiftly once a national innovation system began to focus on specific targets.

²² *China's Electronics Industry 2004*, p. 86.

²³ *China's Electronics Industry 2004*, p. 87.

China is still basically in the emulation phase of industrial development in semiconductors, but signal advances are already being made. National Jiaotong University, for example, recently developed China's first DSP chip, a 16-bit DSP produced by SMIC using a 180nm process, packaged and tested by local firms in Shanghai. Even though it can only compare with low-end chips sold by companies like Texas Instruments, its development surprised many industry observers. Developments in closely related sectors, like telecommunications, also suggest that Chinese industrial planners are aggressively seeking to use the scale and scope of local markets to establish new standards.²⁴ Even at less advanced levels of technology, such strategies will help local manufacturers build up the financial resources necessary to invest much more heavily in applied research and, eventually, basic research.

Electronics Research in China

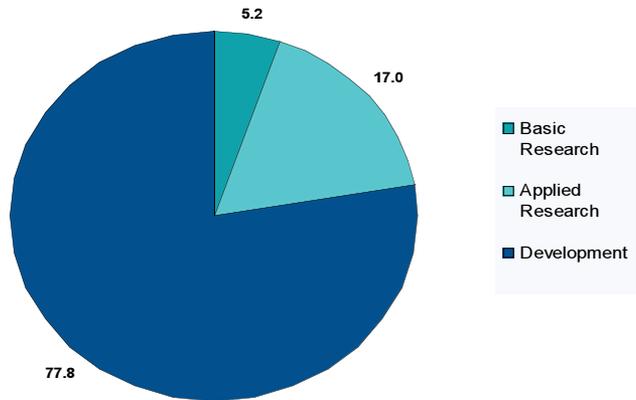
China's electronics research base was hobbled by the legacy of a Soviet-style science and technology system. During the 1980s and 1990s, rapid moves were made to jettison this legacy at the national level by emulating best practices in the United States and Western Europe. The Ministry of Science and Technology, the Chinese Academy of Sciences, the Chinese Academy of Engineering, a new Ministry of Information Industries, and a new National Science Foundation—together with the Ministry of Education which funds universities—lie at the core of official

²⁴ See Richard P. Suttmeier and Yao Xiangkui, "China's Post-WTO Technology Policy: Standards, Software, and the Changing Nature of Technonationalism," NBR Special Report No. 7, Seattle, WA: The National Bureau of Asian Research, May 2004. The authors see Chinese standards policy as motivated by "neo-technonationalism," in which technological development in support of national economic and security interests is pursued through leveraging the opportunities presented by globalization for national advantage. They depict a China that to this point in time has benefited in absolute terms from technology transfer into the country but still losing out in relative terms. Paying substantial royalties to foreign corporations leaves it in a "patent trap" that it fully intends to escape, partly by designing its own technology standards.

reform efforts. Between the mid-1990s and the present, aggregate national R&D expenditures have risen from about .5 percent of GDP to over 1 percent.²⁵ Although still much lower than the 2 to 2.5 percent registered in the most advanced countries, the rate of change is staggering, particularly when China has confronted so many other pressing needs. The National Science Foundation of China (NSFC) budget doubled between 1996 and 2000, and again between 2000 and 2003. Meanwhile, undergraduate and graduate enrollments in science and engineering programs at Chinese universities and institutes increased by more than 25 percent per year in the early years of the 21st century.

As Figures B and C indicate, most investment in research came from Chinese firms, and again, most of this still really remains focused on development. Across the board, nevertheless, applied research is on the rise.

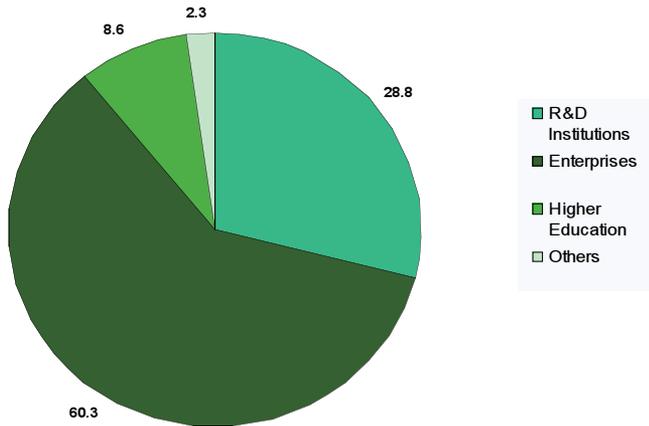
Figure B
Type of Work Performed by Research Institutions in 2000 (percent)



Source: MOST. China Science and Technology Statistics Data Book 2001

25 For an excellent overview, see Deh-I Hsiung, "An Evaluation of China's Science & Technology System and its Impact on the Research Community," *Special Report for the Environment, Science & Technology Section*, U.S. Embassy, Beijing, Summer 2002.

Figure C
R&D Expenditure by Research Sector in 2000 (percent)



Source: MOST. China Science and Technology Statistics Data Book 2001.

As would be expected at this stage of China's development, the R&D intensity of Chinese firms is low in comparison with firms from advanced industrial countries. Still, patent applications by firms and research institutes rose from 83,000 in 1995 to over 170,000 five years later. And in response to financial incentives put in place by the government, China's rank in the global index of peer-reviewed and cited papers rose from seventh in the world to third.

Clearly, China's government is trying to compensate in part for the under-investment in R&D by local companies and to lay the groundwork for a fully functioning national innovation system. University researchers are forced to retire early (age 60 for men, 55 for women) to make room for new scholars. The resources of the Chinese Academy of Sciences (CAS) are being expanded rapidly. CAS itself runs an elite graduate school, with research as its focal point. Through the Hundred Talents Program administered by the

NSFC, it is trying to recruit star professors from leading foreign universities.²⁶ (Salaries offered are far in excess of typical academic salaries in China, a generous research allowance is provided, and a grant of RMB200,000 is made for the purchase of a home.) When the program started in 1995, seven recruits, with an average age of 34 came from abroad. By 2001, recruiting was at the level of 130-190 per year.²⁷ Where Chinese universities have a difficult time differentiating between excellent and just competent performers, or among various fields of study, CAS is deliberately attempting to emulate high-level science and engineering faculties in the United States. If there is a Chinese MIT in China's future, it may well be located outside conventional academic boundaries and in the elite research institutes of CAS.²⁸

Two of the most prominent of those institutes are the Institute of Semiconductors and the Institute of Software. Although competition among all CAS institutes for funding is intense, these institutes and their branches across the country are flourishing. They are typically led by scholars with significant research experience overseas, and they are well known for their burgeoning links to analogous research networks in the United States. CAS scholars routinely travel abroad for conferences, although U.S. visa restrictions have begun to impede this activity. Anecdotes abound concerning recent difficulties encountered. (Indeed, several of the appointments we had scheduled well in advance were cancelled at

²⁶ For relevant background, see Cong Cao and Richard P. Suttmeier, "China's New Scientific Elite: Distinguished Young Scientists, the Research Environment and the Hopes for Chinese Science," *The China Quarterly*, no. 4, 2001, pp. 960-984.

²⁷ Hsiung, p. 26.

²⁸ To some observers, it is ironic that China moved along this specialized lab route during the same era that the United States was burying the remains of its famous Bell Labs. It is, perhaps, no coincidence that President Bush's Council of Advisors on Science and Technology has recently raised the issue once more and called for the development of a substitute national organ. See The President's Council of Advisors on Science and Technology, *Sustaining the Nation's Innovation Ecosystems: Report on Information Technology Manufacturing and Competitiveness*, Washington, DC, January 2004, p. 25.

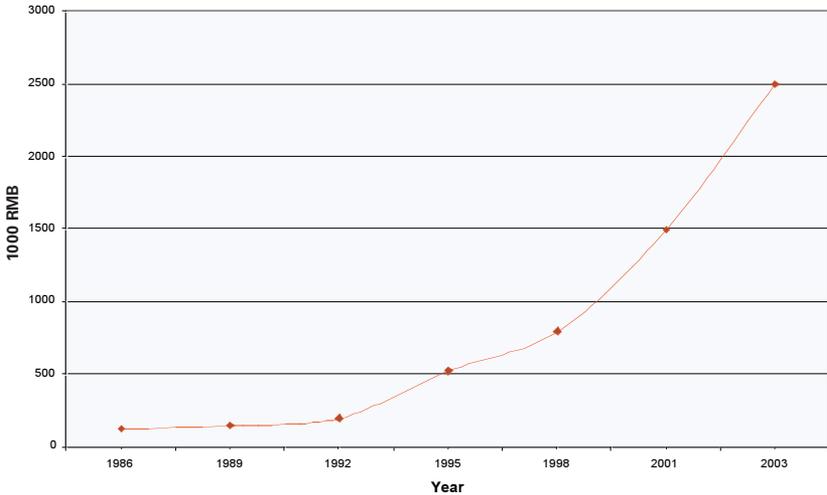
the last moment in explicit retaliation for visa denials or delays; we were able to reverse a couple of these decisions after providing an extensive explanation of the non-governmental nature of our visit.)

Related organizational innovations followed the creation of the Chinese Academy of Engineering (CAE) in 1994. The CAE has a more specific mandate to provide government and firms (often spin-offs from work done in CAS institutes) with advice on the future development of engineering S&T. Information and electronic engineering is one of the seven main divisions of the CAE. Among other things, the division seeks to organize and promote domestic and international collaborations. Another division focuses on chemical, metallurgical, and materials engineering. Unlike CAS, the modus operandi of the CAE divisions is to work through university engineering departments. Thus far, their key partner is Tsinghua University. During the last couple of years, more prominence has been given to deepening the management skills of engineering graduates coming out of Tsinghua and other prestigious universities.

The National Science Foundation of China has also been more intensively promoting research of interest to China's semiconductor manufacturers, especially in life sciences and material sciences. The Foundation provides research grants on the basis of national competitions. Recently, the success rate has been approximately 16 percent of applications; a decision was taken two or three years ago to concentrate resources on larger projects with the most promising prospects for near-term results. (The total NSFC budget increased from RMB 80 million in 1986 to RMB 2.6 billion in 2002; its average research grant now exceeds RMB 172,000, but key or major projects can be funded at the level of RMB 1-5 million, for up to five years. In 2001, engineering and materials sciences accounted for 548 grants for a total of RMB 110 million, the second largest category after life sciences.²⁹)

²⁹ Hsiung., p. 29-30.

Figure D
National Science Foundation of China Budget (1986-2003)



Source: *NSFC 2000 Annual Report*. National Natural Science Foundation of China

Expanding the Human Resource Pool

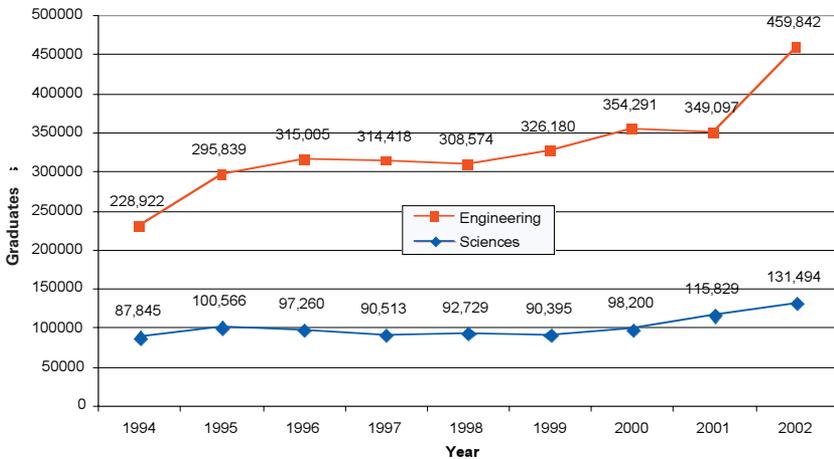
A serious national commitment to building a solid foundation in the medium term for advanced industrial production and innovation in China is evident in the rapid expansion of university-level teaching programs. Human resources are, of course, the core of any applied or basic research base in the information technology industries, including semiconductors. In this regard, careful consideration must be given to the scale and scope of what China is now accomplishing.

One broad measure of the national educational commitment is an astounding and rapidly accelerating increase in the number of Chinese university students over the past decade from institutions of higher learning, particularly in the fields of science and engineering. The Chinese data presented below include universities and institutes, and are broadly consistent with new U.S. National

Science Foundation data, which focuses on a narrower base. Figure E shows the numbers of students who graduated with a bachelors-level degree in science or engineering in China from 1994 through 2002.

Figure E

Graduates of Institutions of Higher Learning in China by Field of Study



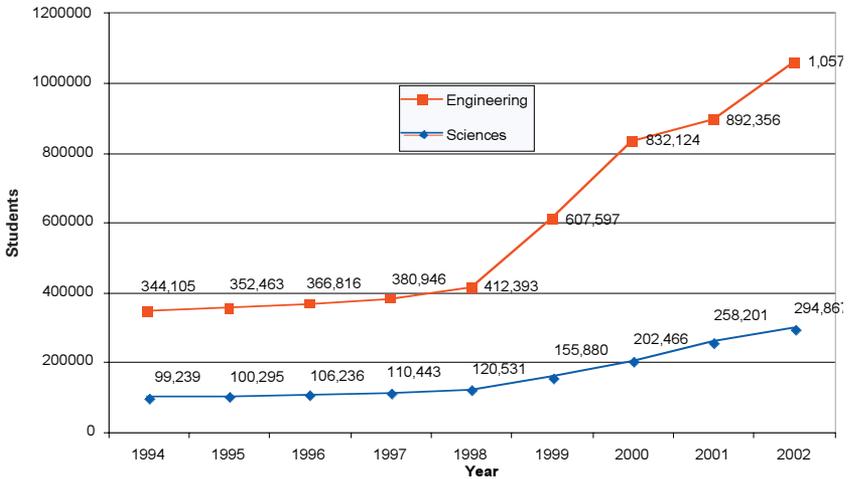
Source: China Statistical Yearbook on Science and Technology 2003

National Bureau of Statistics, Ministry of Science and Technology, China p.24

The number of bachelors-level *degrees awarded* in engineering alone rose from 229,000 in 1994 to 460,000 in 2001, an increase of 231,000, or over 100 percent. (The spike in the year 2002, about 110,000 graduates, is particularly notable.) The rise in bachelors-level degrees awarded in the sciences was not as dramatic as in engineering, but was still very significant. There were 131,000 graduates in 2002, an increase of 43,000 since 1996, or about 50 percent. These figures are remarkable in themselves. But it is the slope of the increases in *engineering* in 2001 that bears further scrutiny.

Figure F indicates the number of individuals *entering* bachelors-level science and engineering programs in China during the same time period, 1994 to 2001.

Figure F
Undergraduate Entrants in Institutions of Higher Learning in China by Field of Study



Source: China Statistical Yearbook on Science and Technology 2003

National Bureau of Statistics, Ministry of Science and Technology, China p.22

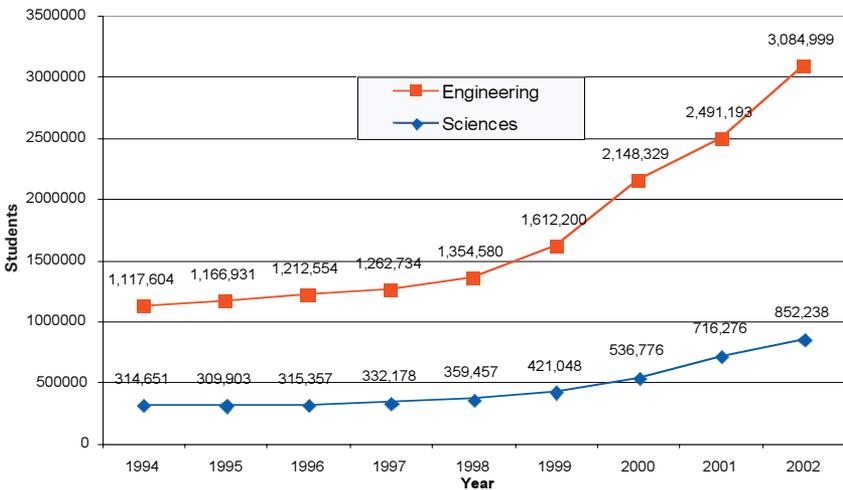
After 1998, there is an obvious and dramatic acceleration of the numbers of young people entering higher education in both science and engineering. During the next five years, the number of students entering bachelors-level engineering programs catapulted from 412,000 in 1998 to over a million in 2002, an increase of 645,000, or about 155 percent. Calculated as a cohort moving through a typical four-year program, the expected number of engineering students being trained at the bachelors-level in China in 2002 would have been on the order of 3,400,000 students.

The same analysis for aspiring scientists yields smaller yet still impressive numbers. By 2002, the number of students entering science programs totaled 295,000, an increase of 174,000 over the 1998 figure, or 144 percent. Again, if we assume a cohort moving through a four-year program, then the number of scientists being training at the bachelors-level in China approximated 910,000 in the year 2002.

For both categories—students entering science programs and students entering engineering programs—one would expect some attrition; this is borne out in Figure G, which shows the numbers of scientists and engineers officially *enrolled* in bachelors-level programs for the period 1994-2002.

Figure G

Undergraduate Enrollment of Institutions of Higher Learning in China by Field of Study



Source: China Statistical Yearbook on Science and Technology 2003

National Bureau of Statistics, Ministry of Science and Technology; China p.23

In 2002, students enrolled in bachelors-level engineering programs numbered nearly 3,100,000, while 852,000 were enrolled in bachelors-level science programs. If all engineering and science students entering in 1999 through 2002 had remained in school, the expected number of enrollees would have been 3.4 million and 910,000 respectively. Accordingly, the attrition rate is approximately nine percent in engineering programs and seven percent in science programs.

These calculations provide a basis for projecting the numbers of bachelors-level graduates who will be available either for entrance

into the Chinese workforce or for further graduate education in science and engineering. We know the number of students entering bachelors-level science and engineering programs from 1999 through 2002. If we conservatively assume an attrition rate of 10 percent, we can make an educated guess regarding the numbers of students likely to receive such degrees for the period 2003 through 2006. (See Table B.)

Table B:
Estimated Numbers of Chinese Science and Engineering Degrees

Awarded at the Bachelors-level—2003-2006 (in thousands)

<u>Year</u>	<u>Science</u>	<u>Engineering</u>
2003	140	547
2004	182	749
2005	232	803
2006	266	951

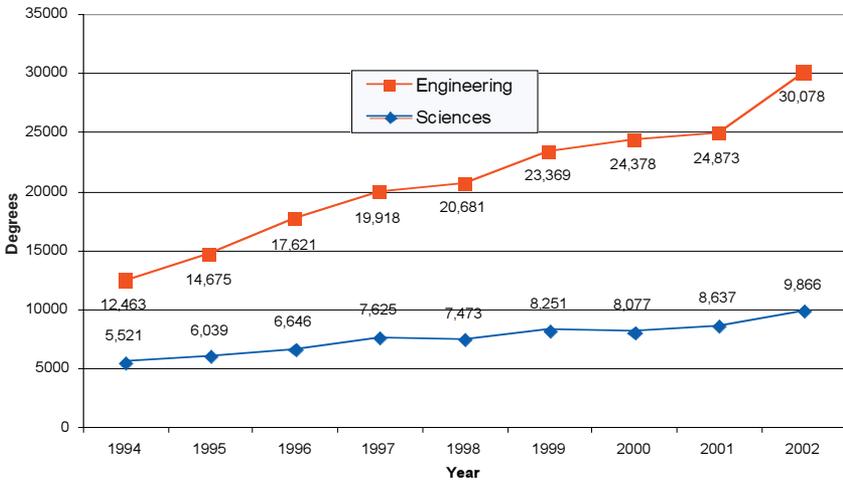
Source: Calculated from Figures E through G above.

Table B is of course only a projection. But barring an economic meltdown in the region, military conflict involving China, or large-scale civil strife within the country, these numbers are very likely to be realized or exceeded.

Analysts can debate whether or not the supply of talent creates its own demand. And the Chinese economy may or may not be able to shift quickly to higher value-added work in semiconductors and other industries. But the numbers analyzed above do indicate that Chinese national education policy is clearly gearing up to promote

such a transition. The point is reinforced by an analysis of the production of masters- and doctoral-level scientists and engineers, as documented in Figure H.

Figure H
Graduate Enrollment of Master Degree and Above in China by Field of Study



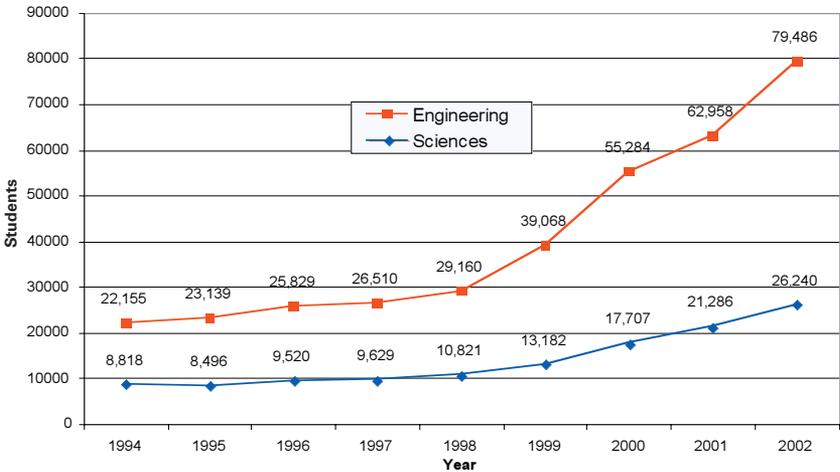
Source: China Statistical Yearbook on Science and Technology 2003

National Bureau of Statistics, Ministry of Science and Technology, China p.24

Based on Chinese data, Figure H indicates the general trend. Although NSF calculations result in lower numbers, the Chinese report is quite consistent with the data presented in Figure E (above) on bachelors-level graduates in engineering and science. There is, once again, a remarkably steady increase in the numbers of students receiving advanced degrees in science and engineering between 1994 and 2002, the last year for which Chinese source statistics are available. Figure H shows that from 1994 to 2002, the number of students graduating with masters-level degrees and above in engineering soared from 12,400 to 30,100, an increase of about 142 percent. As with undergraduate engineering students, the spike for graduate students in 2002 is also quite pronounced.

Growth in the number of students earning graduate degrees in science was smooth and consistent from 1994 through 2002, ranging from 5,500 to 9,900 respectively, amounting to an increase of about 79 percent over the whole period. Interestingly, the number of science degrees granted, at both undergraduate and graduate levels, does not spike in the year 2002. While scientific training remains important, the real emphasis—especially after 1998—has been placed on the field of engineering. Figures I and J give these trends graphical expression.

Figure I
Graduate Entrants of Master Degree and Above in China by Field of Study

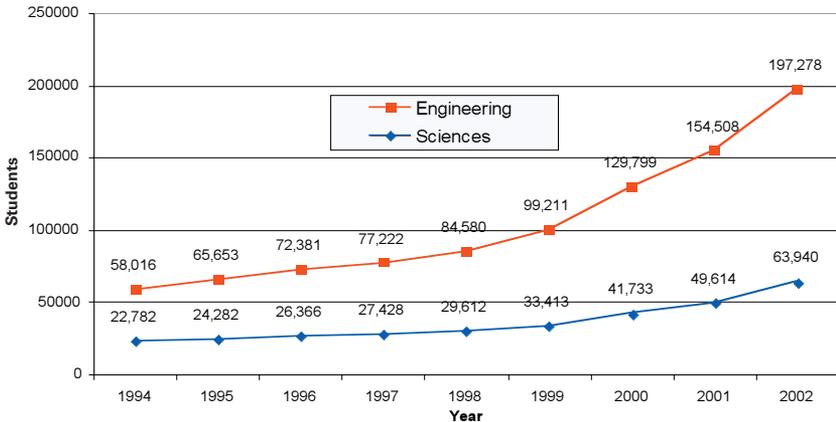


Source: China Statistical Yearbook on Science and Technology 2003
 National Bureau of Statistics, Ministry of Science and Technology, China p.22

As Figure I indicates, the number of students entering graduate training programs in engineering began to increase precipitously after 1998, rising from 29,100 to 79,500 in 2002. This represents an increase of about 173 percent, compared with approximately 32 percent growth for the previous five years, 1994 to 1998. There was also a quite steep, if somewhat more moderate, increase in the number of science students entering graduate programs in China

between 1998 and 2002, an increase of almost 143 percent, which may be compared with growth of only about 23 percent in the five years before 1998. As with bachelors-level enrollments in Chinese science and engineering programs, a number of insights can be gleaned from the overall numbers of students matriculating at the masters-level and above. Figure J shows a strong upward swing in enrollments in both engineering and science graduate programs, accelerating after 1998.

Figure J
Undergraduate Enrollment of Master Degree in China by Field of Study



Source: China Statistical Yearbook on Science and Technology 2003
 National Bureau of Statistics, Ministry of Science and Technology, China p.23

As of 2002, Figure J indicates that 197,300 students were enrolled in graduate engineering programs, and that 64,000 students were matriculating in graduate science programs at the masters-level and above.

While it is more difficult to calculate attrition rates in graduate science and engineering programs, we can still get a rough idea of the numbers of post-graduate degrees likely to be awarded in the years immediately ahead. Like Table B above, Table C adapts the data and assumes an attrition rate of 10 percent.

Table C
Estimated Numbers of Chinese Science and Engineering Degrees

Awarded at the Masters-level and Above—2003-2006 (in thousands)

<u>Year</u>	<u>Science</u>	<u>Engineering</u>
2003	11.9	35.2
2004	15.9	49.8
2005	19.2	56.7
2006	23.6	71.6

Source: Calculated from Figures H through J above.

Even if an attrition rate of 20 or even 30 percent is assumed, in time this rate of growth will place China in the first rank of technologically advanced economies. The impact is already beginning to be felt in the semiconductor industry and in associated information technology industries, both upstream and downstream.

The Prospects for High-Technology Innovation in China in Comparative Perspective

The quantity of human resources available to Chinese industry now and in the future does not necessarily translate directly into an internationally competitive labor force of high quality. But large numbers of adequately trained and relatively inexpensive engineers and scientists are quite likely to be able to compete in fields where technologies are reasonably stable and most innovations are of an incremental nature. Moreover, as the Chinese economy expands, far more robust resources are likely to be made available to Chinese

universities for the development of higher quality systems of innovation. Because so much has already been accomplished in the establishment of nation-wide production facilities for semiconductors, it is likely that one of the first such systems—a solid base for applied, then basic research—will appear in this industry.

Not so many years ago, applied research in the United States was considered to be far less important than it is today. The lag time for comprehending its importance was even greater in Europe and Japan. It would be folly to assume that Chinese industrialists are not seeking to replicate the success of the semiconductor industry in the world's most advanced economies, partly by emulating their move up the research ladder from product development to applied research, and eventually to basic science

Many observers were caught off guard by the rapid rise of a competitive Japanese semiconductor industry in the 1980s; others watched with incredulity as the Korean IDM and Taiwanese foundry models later gained significant global traction and competitiveness. The difference between these three cases and the Chinese case does not lie in relative work ethics; Chinese students are among the most able and most motivated in the world. It does not lie in ambition, for there is no doubt that China's leadership aims to return China to the global prominence it once enjoyed. China is simply a late mover in the industry, and the key to catching up lies in the sheer volume and improving quality of the manpower available to strategic industries like semiconductors.

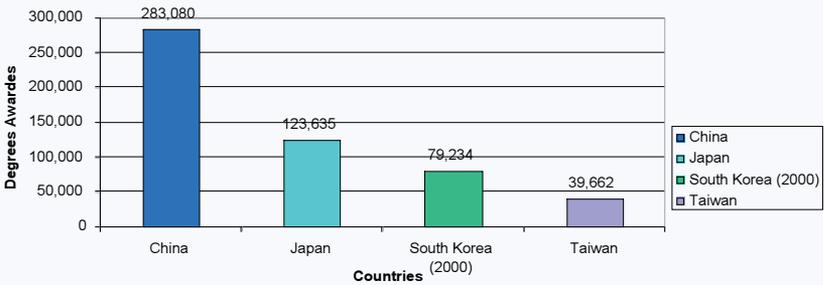
Semiconductor designers and manufacturers in the United States and other advanced economies cannot assume that they will be able in the near and medium term consistently to come up with leapfrog technologies that will keep leadership positions within the industry beyond the reach of China. In any event, recent history has amply demonstrated that the inventors of breakthrough technologies are not always the ones to reap the rewards. Smart 'follower strategies' have long been evident within the industry. Comparative

educational data complements the statistics arrayed above and suggests the scope for a regional and global redistribution in the human resources available in the medium-term for innovation in semiconductors and cognate sectors.

In comparative data on bachelors degrees awarded in Asia in 2001, the latest year for which National Science Foundation (NSF) statistics are available, it is easy to find discrepancies with Chinese source data. Some of the differences are accounted for by the fact that agricultural sciences and social/behavioral sciences data are excluded from the NSF data sets; there are many more agricultural science and engineering degrees awarded in China than in other countries. Chinese data also encompasses a wider set of institutions of higher learning. Nevertheless, the latest NSF data reinforce the same broad trends highlighted above.

As Figure K clearly indicates, in 2001 China had already far surpassed its Asian neighbors in terms of the number of bachelors degrees awarded in science and engineering.

Figure K
Bachelors Degrees Awarded in Science and Engineering in 2001, Various Countries



*Excludes Agricultural Sciences and Social Behavioral Sciences

Source: Science and Engineering Indicators 2004

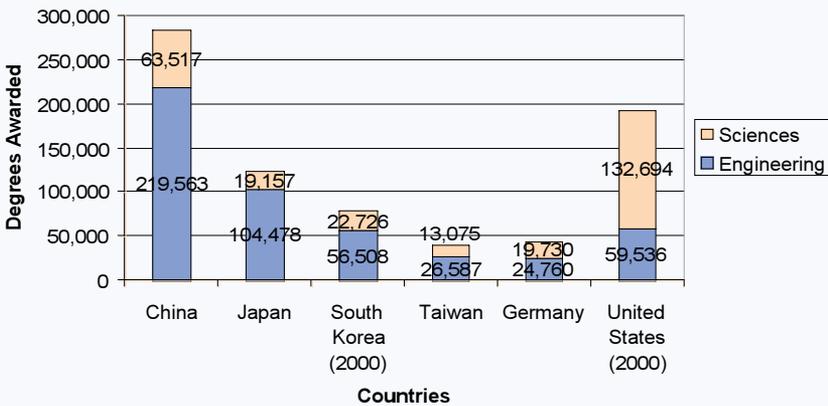
National Science Foundation. United States. Appendix Table 2-33

In this regard, China exceeded its closest Asian competitor, Japan, by a factor of more than two. South Korea and Taiwan counted as distant third and fourth placeholders. Again, this tremen-

dous lead in trained technologists is likely to have a cumulative impact, soon launching China into the first tier of industrial economies. As a techno-nationalist state, Japan has sought to train a very high proportion of its workforce in the scientific and engineering disciplines, but the aggregate Chinese population advantage seems already to be forcing adjustments.

By 2001, China had attained number one leadership status in the combined production of undergraduate science and engineering degrees, surpassing even the United States. As Figure L illustrates, the United States still leads the world in the number of undergraduate science degrees conferred, but China dwarfs even the closest competitor in the sheer volume of engineering degrees awarded. Moreover, when U.S. undergraduate science training is excluded, China is number one on all measures, overpowering even Germany by a factor of seven to one. This likely foreshadows even more dramatic developments to come.

Figure L
Bachelors Degrees Awarded in Science and Engineering in 2001, Various Countries



*Excludes Agricultural Sciences and Social Behavioral Sciences

Source: Science and Engineering Indicators 2004

National Science Foundation. United States. Appendix Table 2-33

In light of the current *outsourcing/offshoring debate* within the United States, it is worth underlining the magnitude of the differential in engineering training between China and the United States, which in 2001 produced 220,000 and 60,000 undergraduate engineers respectively. Estimates vary, but one oft-cited figure is that hiring a ‘fully loaded’ U.S. engineer costs between four and six times as much as his or her Chinese counterpart. As more Chinese engineers come on line, and the infrastructure for data transmission matures, it seems only a matter of time before even highly-skilled engineering jobs move to where the labor is abundant and relatively inexpensive.

It is also important to emphasize the fact that as many as half of the 60,000 or fewer engineers now graduated annually by U.S. universities are not American citizens. Many of these graduates are now opting or being forced by U.S. visa and immigration policies to return to their countries of origin. This is, in part, an unintended consequence of security measures taken to protect the United States in the aftermath of the 9/11 terrorist attacks. But it is also a reflection of the growing opportunities for U.S.-trained engineers, who may have worked after graduation for companies in the United States and whose value to their countries of origin is thereby enhanced. For the United States, and for the first time, this situation signals impending brain drain; whereas for China, it is the beginning of brain ‘regain.’

Conclusion

Significant adjustments lie ahead for the world-wide semiconductor industry. Initially, China’s rise as a key manufacturing center will have dramatic consequences on both the demand and supply side of global markets. Based on experience elsewhere, however, the longer term consequences are likely to be the more profound. From

the point of view of current industry leaders, much process innovation and applied research seems certain to migrate to China in the near to medium term.

Eventually, as Chinese research institutes and universities improve through the efforts of a burgeoning population of trained engineers and scientists, pre-competitive and even basic research is likely to expand as well. In related sectors, we have already seen a willingness on the part of Chinese authorities to leverage the promise and scope of national markets to establish the kinds of technical standards that allowed leading enterprises to flourish globally.³⁰ Similar efforts will surely characterize the future of the semiconductor industry. They should be interpreted and assessed in a wider strategic and historical context.

The question debated in foreign policy circles just a few years ago focused on whether China should best be viewed as a future rival, partner, or competitor has now become much more subtle. We are beginning to witness the emergence of a deeper appreciation of the complexity of China's governing structure, the dynamism and fragility of the social foundations of national political authority, tensions among reformist economic elites, a traditional military establishment, and relatively autonomous provincial and local officials.

Techno-nationalists in China, however, invoke memories of the experience of the early twentieth century to underpin policies designed to accelerate technology transfer without compromising national independence. This has led many observers to the conclusion that China will eventually seek to consolidate its power regionally, strive to offset or balance U.S. power within its borders, and even compete more directly with the United States and other advanced countries in areas where strategic resources like petroleum are at stake.

Such a view does not necessarily portend future security

³⁰ See Alberto Gabriele, "S & T Policies and Technical Progress in China's Industry," *Review of International Political Economy*, vol. 9, no. 2, Summer 2002, pp. 333-373.

conflicts, but there is certainly room for deep divisions regarding advisable foreign policy reactions by the United States and others. It is entirely plausible, and certainly well within the realm of historical experience, that a China intent on balancing U.S. power would in the short and medium run seek to deepen and strengthen bilateral relations with the United States. In addition to seeking alternative and competing sources of technology, establishing strong ties with the United States would constitute an expeditious way to advance the Chinese economy. Strategic realists in the United States therefore advocate a response to China characterized by caution and careful cost-benefit calculations. Although they begin with a different perspective, advocates of assertive policies aimed at promoting human rights come to similar conclusions. Conversely, those with a more optimistic cast of mind believe that short-term calculations are unnecessary and even counter-productive, since deeper bilateral involvement will inevitably lock China into global webs of interdependence, especially in strategic industries—like semiconductors—that cannot easily be sustained inside relatively closed national markets.

Partly because of the existence of those alternative sources of technology, hard-liners in the United States have found it difficult to build a consensus in support of containing or undercutting expanding Chinese power. They have increasingly found themselves confronting the demand on the part of both prominent businesses and leading American allies for consistent policies designed to engage China economically, to promote gradual change in its internal governance practices, and even to acquiesce when such change is not forthcoming.³¹ American businesses directly linked to the U.S. national defense base have increasingly found themselves confronting the reality that they cannot achieve necessary

³¹ Realists continue to insist that even such a transformation is unlikely to move Chinese foreign policy in the direction foreign businesses might hope. "Whether China is democratic and deeply enmeshed in the global economy or autocratic and autarkic will have little effect on its behavior." John Mearsheimer, *The Tragedy of Great Power Politics*, New York: W.W. Norton, 2003, p. 4.

economies of scale in new technologies if they and only they bear the brunt of export controls aimed at keeping China a generation or two behind the United States. China's current and potential human capital, together with the gradual development of a low-cost research and manufacturing base in China, above all in the semiconductor industry, is now building enormous pressures in the same direction. In such a context, the offshore movement of human and financial capital in the semiconductor and related industries looks like a phenomenon that has only just begun.

It is still possible that nationalist impulses in both the United States and China could feed off one another and make coherent policies more difficult to craft. Intentions, more than capabilities, are key. It is sobering to note that Franklin Roosevelt's 1935 opinion on the difficulty of assessing China's direction remains apt, and as a careful student of the subject notes:

[There remains a tendency] to infer Chinese intentions from Chinese capabilities alone. China bashers thus rant away, oblivious of the impact that their words and deeds have on Chinese nationalists, who not surprisingly respond with equally virulent America bashing. Such diatribes feed off one another, eroding the trust that binds the U.S.-China relationship. Even more ominously, hard-liners on both sides, seeking to save face, advocate 'demonstrations of resolve,' increasing the likelihood that the U.S.-China conflict they predict will come to pass.³²

The challenge is to find practical steps to accommodate China's rise without falling into either Panglossian dreams of inexorable harmony or pessimistic self-fulfilling prophecies of future disaster. One doesn't have to search very far to find indications of a classic strategic rivalry between the United States and China. China is building a blue-water navy, and the United States is surely

³² Peter Hays Gries, *China's New Nationalism*, Berkeley: University of California Press, 2004, p. 137.

war gaming. Caricature images of Taiwan and Japan remain focal points for an authoritarian regime playing another deadly serious game, this one of using the volatile tool of nationalism to bolster the ideological foundation of its power. But there is no self-evident reason why much of this competitive impulse cannot be displaced to the mixed conflictual/cooperative arena of global capitalism. Since 1945 and 1989, this has happened in most other parts of the world. Why not here?

Developments in the semiconductor industry suggest just such a scenario. Given the potential size of its internal market and the vast scale of the human and financial human resources currently building up its national engineering base, China will fairly soon become a major force in process innovation and applied research in this field. But no country has been able to insulate comparable national systems; even if they remain rooted in national and regional foundations, they are in fact becoming ever more deeply integrated. Especially because the scale of investment required even for incremental breakthroughs is so high, this is particularly evident at the pre-competitive level of research, where collaborative, cross-national research is mushrooming. How can China resist such a tendency, especially if the manufacturing base it is now building can only stay competitive if it learns to innovate?

Strategic puzzles abound in this industry. Imagine a country where many citizens of a 'strategic rival' armed to the teeth currently live inside its territory and work hard to build up its companies, companies that will compete directly with companies based in their own homeland. That's the present situation in the semiconductor industry in China. Now imagine one US company, Motorola, claiming to be recentering future corporate operations on Asia and specifically in China, while others hesitate to develop any ideas there that they could not afford to lose. Which specific interests should US war gamers seek to defend? Those of the thousands of Taiwanese currently living in Shanghai and potentially being

threatened by Taiwanese counterstrike forces? Motorola's, or its more cautious American competitors?

It remains the case that basic research in this and other IT sectors continues to be dominated by the United States. Since 1945, this has clearly remained a national strategic priority for the country, arguably the core pillar of its enduring hegemonic position within the international system.³³ As the comparative data above suggests, there evidently remains a consensus inside the United States that substantial human and financial resources should continue to be invested in the highest level of scientific research in the universities and laboratories currently at the cutting edge of semiconductor-related innovation. Given the physical limits now coming into view in the development of current technologies, this now likely means substantially more investment will likely soon be flooding into advanced materials and biochemistry for the post-silicon era. No other country, including China, is yet behaving in a similar manner. Like China, the more typical country focuses national investments in engineering and science education clearly on the engineering side, where payoffs seem more certain in the immediate future. As long as this remains the case, China's aspirations to 'leapfrog' to next-generation integrated circuits can be dismissed as wishful thinking.

Certainly from the point of view of long-term balance-of-power theorizing, however, it remains surprising that American dominance in the natural sciences has not yet stimulated serious strategic responses. Perhaps it will someday, and structural realists can always comfort themselves with the notion that eventually they are bound to be right. But it could be that something else is at work. Leading edge science in the United States has depended not only upon substantial public and private financial investment, but also on exceptional intellectual openness to and from the rest of the world.

³³ Robert L. Paarlberg, "Knowledge as Power: Science, Military Dominance, and U.S. Security," *International Security*, vol. 29, no. 1, Summer 2004, pp. 122-151.

It has sought and attracted the best brains from around the world, but it has also not strenuously impeded those brains from leaving the territorial domain of the United States. On the basis of new science, it spawns new technologies, creates new industries, establishes competitors, and primes the pump for pre-competitive collaboration by rival firms. Certainly this remains the situation in the semiconductor and closely related industries.

Two developments could change that situation. The Americans could kill the goose that lays the golden egg by eroding its scientific base, by diverting financial investment or moving to close off either end of the global human resource flow. Certainly the American semiconductor industry itself is worried that just such reversals are now underway, as mounting federal budget deficits threaten to constrain future financial investments and terrorism hysteria impedes the flow of scientific brains to the United States.

At the same time, China could seriously attempt to import and adapt foreign science and technology without allowing foreigners to benefit and without reciprocating in the fullness of time. Certainly it is easy to imagine a couple of Chinese national champions using their national market advantages (and linguistic insulation) eventually to emerge at the highest level of global competition in the semiconductor industry and in cognate or successor industries. It is also not too difficult to imagine their American counterparts accommodating them and even collaborating with them.

What remains extremely difficult to imagine, however, is acquiescence on the part of the American government, and American society more generally, to a secondary position. An American strategy of engagement with China, the only sensible strategy at the moment, could have the effect not only of forestalling overt balancing behavior by China but also by the United States itself. Serious engagement, however, does not mean simple acceptance of market facts. To the extent it really is possible to create images of 'us' and 'them' that really do construct the world in which we

ultimately live, then serious engagement means crafting policies that both steer toward desirable outcomes and away from undesirable ones. Some political scientists use the metaphor of carrots and sticks, while others prefer deterrence and reassurance. Economists like incentives and disincentives. But China is inherently too big and potentially too powerful seriously to be steered anywhere. Sensing this, even on the pages of *International Security* we may begin to detect an emerging consensus.³⁴

Mental images of the status quo, balancing, and globalization may be obscuring more than they clarify. The objective must surely be to bring China fully into the system the United States and its allies have been building and rebuilding since 1945. At its core is a military alliance. Its economy rests on competing (and still mainly national or, at most, regional) markets that are interdependent by design. The leading states cooperating with the United States in maintaining such a system are now structurally inclined either to favor cooperative solutions to difficult systemic problems or to acquiesce in practice when coercive measures are deployed. China should one day be recognized as one of those leading states, and optimists must surely cling to the belief that the system remains flexible enough to accommodate its key interests. They must just as surely hope that deeper engagement will transform or marginalize those interests that are today threatened by the winds of change. Outside of China, in sectors like semiconductors and its likely future successors at the cutting-edge of science and technology, this must surely translate into policies that lean toward market-based competition and lean against market closure. In systemic terms, a synonym for 'leaning' is statesmanship.

34 See, for example, Alastair Iaian Johnston, "Is China a Status Quo Power?" *International Security*, vol. 27, no. 4, Spring 2003, pp. 5-56; Thomas J. Christensen, "Posing Problems without Catching Up: China's Rise and Challenges for U.S. Security Policy," *International Security*, vol. 25, no. 4, Spring 2001, pp. 5-40; and Peter Hays Gries and Thomas J. Christensen, "Correspondence: Power and Resolve in U.S. China Policy," *International Security*, vol. 26, no. 2, Fall 2001, pp. 155-165.

