POLICY RESEARCH WORKING PAPER 4309

Strengthening China's Technological Capability

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The World Bank
Development Research Group
August 2007

Policy Research Working Paper 4309

Abstract

China is increasing its outlay on research and development and seeking to build an innovation system that will deliver quick results not just in absorbing technology but also in pushing the technological envelope. China's spending on R&D rose from 1.1 percent of GDP in 2000 to 1.3 percent of GDP in 2005. On a purchasing power parity basis, China's research outlay was among the world's highest, far greater than that of Brazil, India, or Mexico. Chinese firms are active in the fields of biotechnology, pharmaceuticals, alternative energy sources, and nanotechnology. This surge in spending has been parallel by a sharp increase in patent applications in China, with the bulk of the patents registered in the areas of electronics, information technology, and telecoms. However, of the almost 50,000 patents granted in China, nearly two-thirds were to nonresidents.

This paper considers two questions that are especially important for China. First, how might China go about accelerating technology development? Second, what measures could most cost-effectively deliver the desired outcomes? It concludes that although the level of financing for R&D is certainly important, technological advance is closely keyed to absorptive capacity which is a function of the volume and quality of talent and the depth as well as the heterogeneity of research experience. It is also a function of how companies maximize the commercial benefits of research and development, and the coordination of research with production and marketing.

This paper—a product of the Development Research Group—is part of a larger effort in the department to analyze innovation systems in East Asia. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at syusuf@worldbank.org.

Produced by the Research Support Team

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Introduction

In less than 20 years, China mastered a broad range of codified industrial technologies to become the world's leading manufacturer of mass-produced goods. By 2006 China had become the fourth-largest economy in the world and the third-largest trading nation.

China is now aiming higher, preparing to compete with the industrial frontrunners on the basis of industrial production capability in more complex products and services as well as on the basis of industrial innovation and design in a number of fields. To telescope the time needed to achieve this objective, China is increasing its outlays on research and development (R&D) and seeking to build an innovation system that will deliver quick results. China's spending on R&D rose from 1.1 percent of GDP in 2000 to 1.3 percent of GDP in 2005. In absolute terms the growth was even more impressive, because national product increased by an average annual rate of over 9 percent during this period. On a purchasing power parity basis, China's research outlay was among the world's highest, far greater than that of Brazil, India, or Mexico (UNCTAD 2005).[1]

With competitiveness keyed ever more closely to innovation, a progressive upgrading of technology is viewed as a necessity by firms in many industries. In China's case, accelerating the development of technology is acquiring urgency because returns on existing product lines are being squeezed by rising costs and a massive expansion in industrial capacity, both in China and worldwide (Ma, Nguyen, and Xu 2006).[2] By strengthening technological capabilities, Chinese firms can lessen their dependency on foreign sources and raise profit margins. Investing more in technology also will enable China to progressively reduce the energy and resource coefficients of its GDP, and offset an anticipated trend increase in the relative prices of these commodities.[3]

While the advantages of assimilating, applying, incrementally refining and contributing to the march of ever-more complex technologies are obvious, several issues remain to be resolved. Two questions are particularly important for China. First, what is

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[1] How some of this money is being spent on state of the art laboratories is described in "China Supersizes its Science" (2007).

[2] Schott (2006) finds that even though China's exports rank third in the degree of overlap with OECD countries, the prices it receives have been declining over time relative to OECD prices.

[3] China's research effort in the areas of space and defense technologies, as well as cooperative programs with the Brazil, the European Union, and Israel, are described in Sigurdson (2005).

the feasible pace of technology development and, in particular, the scope for pushing the technology frontier outward in a few important scientific fields with the potential for significant industrial spillovers? Second, at China's current level of development, what is the mix of policy initiatives that will cost-effectively deliver the desired rate of progress?

Acquiring Manufacturing Capabilities

To begin answering these questions, one must look first at China's current industrial system and the underlying technological capability. By all accounts, China's industrial base is exceptionally broad. This is in part the result of the industrial strategy initiated in the 1950s, which aimed at achieving a measure of self-sufficiency in a wide range of capital and consumer goods. Guided by this strategy, China built up a geographically dispersed base of heavy industries and, in the 1970s, began investing substantially in manufacturing capacity for light consumer items, farm equipment, and electronics in rural and urban areas. Although during the 1980s, China lagged behind some of its industrializing neighbors, several decades of investment helped create a diversified industrial system, a large pool of engineering and production line skills, and a fund of "learning" from building, running, and maintaining manufacturing facilities by drawing mainly on domestic resources only as Japan and Korea had done earlier.

Since 1980, when China's "open door" policy began integrating China with the global economy, the country's capabilities have been extensively augmented by importing plant and equipment embodying new technologies; by licensing industrial technology; by attracting foreign direct investment (FDI); through the circulation of knowledge workers, mainly Chinese trained abroad, who have become an important conduit for technology transfer; and more recently, through the help of domestic R&D. In its effort to strengthen industry, China has been aided by two closely related trends. First, because of the maturing of certain technologies and the parallel growth of consumer markets, many manufactures have become standardized commodities. Second, the very process of "commodification" has been supported by the codifying of the associated technologies, some embedded in equipment, others available from suppliers. These changes have made it easier to absorb new production methods and quickly achieve high levels of efficiency. These developments have also made the production of mass market items increasingly mobile globally.

China has benefited more from these trends than most other countries, because it was better prepared to assimilate manufacturing technology, for a number of reasons. These included the advantages of a potentially huge domestic market, the early as well as successful penetration of foreign markets in light manufactures, both of which encouraged investment in capacity, and the rapid increase in workers with secondary and tertiary education. Export-led growth was greatly aided by the flow of FDI, as firms in Hong Kong (China) and other neighboring economies shifted production facilities to take advantage of China's low-wage industrial workforce and establish a foothold in the Chinese market (Berger and Lester 1997). As a result of the transfer of hard and soft technologies aided by the growth of human capital, industrial capability has grown by leaps and bounds, facilitated by the elastic supply of rural workers to China's burgeoning industrial cities in strategic locations along the east coast. The buildup has been supported by rising investment in urban, transport, and energy infrastructure, which has helped sustain China's cost advantage, making it the workshop of the world for a range of mass-produced goods.

To what extent is this remarkable achievement related to technological capability and innovation? China has clearly demonstrated a knack for absorbing and harnessing codified technologies far in excess of other industrializing countries. It has also invested heavily in fixed plant, which has lowered the average age of equipment to 7 years (compared with 17 years in the United States) (Boston Consulting Group 2006). At the same time, the number of science and technology workers rose sharply, from 755,000 in 1998 to 1.2 million in 2004 (Shang 2005).

The speed with which China has imitated technologies and mastered production skills has been impressive. However, the degree of innovativeness has been limited. This is most clearly apparent from the composition of China's major manufactured exports and the nature of the commercial innovations associated with China's leading companies.

Computers and peripherals, storage devices, electronic components, other office equipment, consumer electronics, textiles, toys, and footwear make up a large share of China's major exports (Table 1). By 2005 China was the world's largest exporter of information and communication technology–based products, and close to one-third of its exports were classified as "high-tech." Although the domestic value added in the mature electronic products subsector (which includes cathode ray tube TVs and refrigerators) is rising steadily as more components are sourced domestically, indigenous technology inputs are relatively insignificant. The manufacture of computers and office equipment still largely involves the assembly of imported components or locally produced ones based on foreign technologies.

Table 1: China's Top 25 Exports, 2004

Harmonized code 1988–92 (6 digit level)	Description	Share of China's total exports
847330	Parts and accessories of automatic data-processing machines	4.0
847120	Digital automatic data-processing machines	4.0
847192	Input or output units	4.2
852520	Transmission apparatus	3.1
852990	Parts for radio/TV transmission/receive equipment, nes	2.3
854211	Monolithic integrated circuits, digital	1.9
847193	Computer data storage units	1.5
852190	Video recording or reproduction apparatus not magnetic tape	1.5
901380	Optical devices, appliances	1.4
852110	Video recording or reproducing apparatus, magnetic tape	1.2
852810	Color television receivers/monitors/projectors	1.2
860900	Cargo containers	1.1
850440	Static converters, nes	0.9
852290	Parts and accessories of recorders except cartridges	0.9
271000	Oils petroleum, bituminous, distillates, except crude	0.9
270400	Coke, semi-coke of coal, ignite, peat & retort carbon	0.9
853400	Printed circuits	0.9
640399	Footwear, sole rubber, plastics, uppers of leathers, nes	0.9
847199	Automatic data processing machines and units, nes	0.9
270112	Bituminous coal, not agglomerated	0.8
640299	Footwear, other soles/uppers of rubber or plastics, nes	0.8
420212	Trunks, suitcases, etc, outer surface plastic/textile	0.8
847191	Digital computer CPU with some of storage/input/output	0.8
851999	Sound reproducing apparatus, non-recording, nes	0.7
611030	Pullovers, cardigans, etc. of man-made fiber, knit	0.7
	Total	38.4

Source: UN COMTRADE data obtained through WITS system.

Early innovations by companies such as Stone, Founders, and Lenovo enabled computers to use Chinese characters through additional hardware, such as add-on cards or printers, and word-processing software (Lazonick 2004; Lu and Lazonick 2001).[4] Although Lenovo and Tsinghua Tongfang, for example, have substantial research programs, they have yet to emerge as leaders in their focal product groups. Huawei and ZTE— arguably the most innovative of China's firms—are now able to match their foreign competitors in the optical networking, midrange router market, and second-generation telecoms market, and they are trying to develop homegrown third-generation technologies (Sigurdson 2005; "The Trouble" 2006).

Chinese firms are active in the fields of biotechnology, pharmaceuticals, alternative energy sources, and nanotechnology.[5] They are registering patents, but so far the development of new commercial technologies remains at an early stage. Although there has been a surge in the level of patent applications in China (to more than 130,000 in 2004), the bulk of patents registered are in electronics, information technology, and telecoms (Table 2), and almost half were filed by nonresidents. Of the almost 50,000 patents granted in China, nearly two-thirds were to nonresidents (WIPO 2006). China ranked fourth in the world in 2004 patents granted by the national agency, after the United States, Japan, and the European patent office (WIPO 2006).

These statistics need to be treated with caution, because patenting in a number of fields is to a substantial degree motivated by the desire of firms to accumulate large patent portfolios, often of limited value, to use as bargaining chips in dealing with their competitors (Ziedonis and Hall 2001). Newer firms sometimes register patents as a signaling device to establish their viability (and attract funding), even if the "new" knowledge content and innovation is minor (Hall 2006a).[6] The explosion of patents in the United States in the 1980s occurred partly for these reasons. The more recent rates of patenting in the life sciences and in software represent changing practices among U.S. academic scientists and not necessarily a significant broadening of technological

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[4] The initial focus of innovation and research efforts in China in the late 1970s was on simplifying the printing of Chinese materials. At that time, computers were unable to represent or print thousands of Chinese characters. Printing was still done using lead typesetting, which required workers to select each character manually from a shelf of thousands of Chinese characters (Lazonick 2004; Lu and Lazonick 2001). This process was labor intensive and repetitive; computerization greatly enhanced productivity.

[5] The possibility of introducing fuel cell based cars on a mass scale is being considered in Shanghai.

[6] According to Hall (2006a: 5), "the survey evidence from a number of countries shows rather conclusively that patents are not among the important means to appropriate returns to innovation, except perhaps in pharmaceuticals." Most patents are never cited or worked on; for the leading U.S. universities, the top five patents (usually biomedical ones) account for two-thirds of their patent-related revenue (Mowery 2006).

possibilities (Branstetter and Ogura 2005; Graham and Mowery 2004; Hall 2005; Hall 2006b; Hunt 2006). Sanyal and Jaffe (2004) find that the increase in patents can also be traced to a lowering of examination standards in the United States and overseas. While rising levels of patent litigation reflect changes in the judicial system which makes it easier to assert or defend intellectual property.[7]

Table 2: Number of Patents Filed by and Granted to Chinese Companies

Company	Sector	Number of domestic patents[a]	Number of international patents granted
Huawei	Telecommunications equipment	4,618	78
Haier	Electronics	2,790	32
ZTE	Telecommunications equipment	1,865	8
Lenovo	Information technology	1,665	0
Bao Steel	Steel	403	0
Tsinghua Tongfang	Information technology	324	1
VIMICRO	Information technology	316	0
FAW	Automobile	253	0
Chery	Automobile	231	0
Foundertech	Information technology	146	0
SMIC	Information technology	157	0
CDTT	Telecommunications equipment	132	0
Langchao	Information technology	115	1
TCL	Electronics	86	6

Source: Ma, Nguyen, and Xu 2006.

a. Number of domestic patents includes patents granted and patent applications filed and released (published) by the government patent office.

Chinese companies have been unusually swift in mastering production technologies by leveraging latent capacities nurtured before 1980. However, China's technology capability is in the normal range given its stage of development. China is ascending the technology ladder, by absorbing technology from more advanced countries; by all accounts, it is doing better than its rivals in Southeast Asia. Can the time spent in catching up be shortened significantly? If so, how and at what cost?

International Experience with Technological Change

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[7] The surge in IT related patenting and the increasing frequency with which patent infringement is becoming the basis of threatened or actual legal action has aroused much concern because it threatens innovation and raises its costs (Jaffe and Lerner 2006). A recent supreme court decision in the U.S. points to a raising of the bar on patents and an attempt to contain costly legal battles.

Empirical evidence indicates that the returns from R&D investments can be handsome. Indeed, private returns can average 28 percent, while social returns can be as high as 90-100 percent. The elasticities of total factor productivity with respect to R&D range from 0.03 to 0.38, with higher rates in the United States than in Europe or Japan (Wieser 2005).

Whether and how China can attain these outcomes is an open question, which can be partially illuminated by examining the experience of a few countries.[8] Comparators can be divided into three groups: large industrial countries, such as the United States, Japan, and Germany, that are innovative and leading exporters of complex manufactures; smaller industrial economies that have attained notable levels of innovation in key industries, including Finland, Israel, the Republic of Korea, Sweden, and Taiwan (China); and large industrializing countries, such as Brazil and India, that have become globally competitive producers of a limited range of manufacturers and services through the acquisition of specific technological expertise.

Lessons from Large, Leading Exporting Countries

Several lessons of relevance to China today can be drawn from the experience of these countries. The first is that the breadth and technological eminence of the United States, Japan, and Germany has been built up over a century or more, through the combined efforts and investments of the business sector, the government, and the co-evolution of variety of research and teaching institutions (Mazzoleni 2005). The business sector—in particular, large "anchor" firms—has increasingly taken the lead, through investment in research and even greater spending on development.[9] However, in the United States and to a lesser extent Japan and Germany, the government's technology and education policies, through a variety of programs, many undertaken collaboratively with the private sector, has been critical for technology development; at varying times and to varying degrees, governments have taken the lead in pushing technological

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[8] A recent RAND Corp. assessment classifies China as the only one among the industrializing economies with the best chance of implementing the top 16 technology applications (Silberglitt and others 2006). However, barriers to catching-up remain as described by Wang (2006).

[9] In Silicon Valley, firms such as Lockheed, Hewlett-Packard, Varian, and General Electric were the initial anchor firms (Adams 2005; Agrawal and Cockburn 2003; Lecuyer 2005).

development, both generally and in specific areas. The success of corporate and government efforts has depended on the supply of trained and talented people from and the research conducted by universities and research centers (Mowery 2005). The creation of intermediary institutions—ranging from regional business networks and Fraunhofer Institutes (in Germany) to providers of risk capital, such as the Small Business Innovation Research program (in the United States)—has helped bridge the information gap between universities and businesses. In each of these three countries, tertiary-level institutions for training, research, and technological intermediation carry the imprint of government policy.

In the context of these three quite different countries, the aspects that arguably deserve emphasis include

- The strong impetus for innovation and the institutional framework provided by national and subnational governments, backed by direct funding of research, fiscal and other incentives, the creation of intermediary organizations, and the procurement of products or services; [10]
- The lead taken by major companies (e.g. Novartis, Merck, Sun, Philips and Google) in developing technologies and, in the process, mobilizing the resources of other firms, and the talent in universities;[11]
- The broad scope of technological development and the reinforcement it provided over time—that is, the fact that advances in some sectors pulled advances in others, through what Hirschman 1958(1958) labeled "unbalanced growth." This is important, because an effective innovation system requires approximately equal performance from all its key parts, something that has been captured by the O-ring theory (Kremer 1993). Moreover, as increasing numbers of innovations are at the intersection of several disciplines, technological capability across subsectors and collaboration across industrial boundaries and among firms able to pool specific expertise is becoming the key driver of technological change.

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[10] State-level governments have also been highly active in the United States and Germany (see for example, Jenkins, Leicht, and Wendt 2006).

[11] The corporate sector is now responsible for the bulk of the research conducted, and corporate research activities are conducted on an international scale, in order to fully exploit the knowledge and research potential in other countries (Carlsson 2006).

Technological diversification increases patenting by firms and their R&D spending while reducing the risks from specialization (Garcia-Vega 2006). In many fields, companies are finding that innovations in hardware are insufficient without parallel innovation in associated processes and services. Often—as in the case of Dell, General Electric, IBM, and other companies—services drive the success of products and are the main sources of profit;

- Financial instruments and institutions that permitted the entry of innovative new firms and the growth of dynamic mid-size ones;
- The generation of expertise, which underpins broad technological advance, and the support of such expertise with research of comparable scope (a relatively small number of universities in key urban centers have provided the foundations on which this dynamic technological capability has been built); and
- The creation, to varying degrees, of conditions promoting openness to ideas, heterogeneity among participants conducting research (increasing in teams), and scope for autonomous action; competition among firms, universities, and research entities; and urban knowledge networks ("wikicapital", see Yusuf 2007).

These features were most conspicuous in the United States, which has led in terms of innovativeness. However, in all three countries, the maturing of broad technological capability has taken close to a century, and it is not apparent that the pace was constrained by expenditures on research or technology development.

Lessons from Late-Starting Economies

Late-starting economies offer another perspective on technological capability that is largely consistent with the conditions described above. Brazil, Finland, India, Israel, the Republic of Korea, and Taiwan (China) are now ranking members of the rising technological elite. Their efforts to build an indigenous innovation system began gathering momentum only in the 1970s and the 1980s (Roos, Fernstrom, and Gupta 2005). In the majority of cases, governments took the initiative in creating tertiary level teaching institution and axial research institutes. For example, KAIST (Korea Advanced Institute of Science and Technology), created in 1981 in the Republic of Korea, and ITRI

(Industrial Technology Research Institute), created in 1973 in Taiwan (China), contributed significantly to the strengthening of the technology base. Their efforts were complemented by some expansion in tertiary-level enrollment, although research at universities, basic or applied, initially received little attention (as was the case in Japan and to a lesser extent, Germany). Much of the early efforts were directed toward assimilating foreign technologies. Business firms, whether private or public, took the lead in Brazil, Finland, India, the Republic of Korea, and Taiwan (China); in Israel, the state, especially defense agencies, played a larger role, as did foreign high-tech firms, which tapped the supply of local skills starting in the 1990s.

A few major firms dominated technology development in these countries. In the Republic of Korea, corporations such as Hyundai and Samsung began the shift from technology assimilation to new product development and the quest for systematic innovation. Nokia in Finland; TSMC, Hon Hai Precision, and Acer in Taiwan (China); Embraer and Embraco and some of the agrobusinesses in Brazil all increased their spending on technology at this time, in response to international competitive pressures reinforced by government incentives for R&D. Engagement with foreign multinationals, technology transfer through imports, and global exporting activities contributed to technology development, albeit less in Brazil and India than elsewhere.

From the start of the new millennium, governments in these countries and the OECD (incorporated in the Lisbon Agenda of 2000) have begun placing greater emphasis on the contribution of technology to industrial competitiveness and growth. Governments are committing more resources—public as well as private—to R&D, and they are trying to position universities to support these initiatives by improving the quality of the education they provide, conducting more research, and developing and commercializing technologies through linkages with businesses.[12] Behind these initiatives is a growing recognition that a broadening of technological capability through more and better basic research and more ambitious programs for developing technologies is vital for growth. For countries seeking steady gains in export performance, diversifying the product mix and increasing the share of higher-quality items that command premium prices while

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[12] The European Union, for example, has proposed creating a European Institute of Technology modeled on MIT.

exiting from product lines where returns are being squeezed is the strategy promising the best returns (Hummels and Klenow 2005).

One measure of the development of technological capability in these countries and on the potential for diversification is provided by the statistics for patents registered in the United States between 2001 and 2005. Like articles in refereed scientific journals, patents are only a partial indicator of scientific prowess, because many patents are never used for any purpose (just as a high fraction of scientific papers are never cited or used to advance technology). Patents are also registered by companies for purposes of cross-licensing and to defend against lawsuits. Although such factors limit the usefulness of patent data, the data nonetheless convey a sense of the scale of technology development and the areas in which it is most intense.

By the end of 2006, China ranked 24th in the world in the number of total patents granted by the USPTO, with 3,178 patents. For the five years ending in 2006, it ranked 20th in the world, with 2,053 patents. While these scores represent a significant increase over 2001, when China ranked 24th in the world, patents from China are only now beginning to make their presence felt on the United States Patent and Trademark Office (USPTO).

What is most striking from the USPTO data is the narrow focus of patenting in the sample of countries relative to the United States and Japan. For instance, the top 10 patent classes account for 39 percent of US patents granted to China (Table 3) but just 21 percent for the United States. The main fields of patent dominance (life sciences and semiconductors for the United States, electronic components for Japan) account for much less than 10 percent of all patents in these countries (Tables 4 and 5). By comparison, for Finland, the Republic of Korea, and Taiwan (China), electronics or telecommunications account for 30–40 percent of all patents (Tables 6–8). In addition, a small handful of firms in each of these economies accounts for one-third to one-half of all patents.[13] In the case of China, electronics accounts for close to a quarter of patents (Table 9). Israel also shows two areas of concentration—biotech and software (Table 10). In contrast, in

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[13] Nokia received 24 percent of all patents issued by the USPTO to Finland-based firms. Samsung received 40 percent and LG 17 percent of all Korean patents. The top 10 patenting organizations accounted for 71 percent of patents granted to Korea-based organization between 2001 and 2005.

Brazil, which has few patents, the pattern is fairly diffuse, with some bunching in the agrotechnology and mining sectors (Table 11).

Table 3: Share of Top 10 Patent Classes in Selected Economies, 2001–05

Economy	Share (percent)
United States	20.7
Japan	25.6
Brazil	28.3
Israel	32.4
Taiwan (China)	37.5
China	38.5
Korea, Rep. of	40.0
Finland	43.3

Source: United States Patent and Trademark Office (2007).

Table 4: Top 10 Patent Classes by the Residents in the United States, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	18,203	4.3
438	Semiconductor Device Manufacturing: Process	11,604	2.8
435	Chemistry: Molecular Biology and Microbiology	10,382	2.5
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	7,856	1.9
128	Surgery (includes Class 600)	7,276	1.7
370	Multiplex Communications	7,064	1.7
520	Synthetic Resins or Natural Rubbers (includes Classes 520-528)	7,029	1.7
428	Stock Material or Miscellaneous Articles	6,463	1.5
532	Organic Compounds (includes Classes 532-570)	6,255	1.5
709	Multicomputer Data Transferring (Electrical Computers and Digital Processing Systems)	5,071	1.2
	Total		20.7

Source: United States Patent and Trademark Office (2007).

Table 5: Top 10 Patent Classes by the Residents in Japan, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	7,367	4.4
438	Semiconductor Device Manufacturing: Process	5,920	3.5
428	Stock Material or Miscellaneous Articles	5,032	3.0
347	Incremental Printing of Symbolic Information	4,062	2.4
520	Synthetic Resins or Natural Rubbers (includes Classes 520-528)	3,805	2.2
359	Optics: Systems and Elements	3,715	2.2
365	Static Information Storage and Retrieval	3,437	2.0
345	Computer Graphics Processing and Selective Visual Display Systems	3,348	2.0
430	Radiation Imagery Chemistry: Process, Composition, or Product Thereof	3,340	2.0
399	Electro photography	3,323	2.0
	Total		25.6

Source: United States Patent and Trademark Office (2007).

Table 6: Top 10 Patent Classes by the Residents in Finland, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
455	Telecommunications	563	13.9
370	Multiplex Communications	329	8.1
162	Paper Making and Fiber Liberation	250	6.2
375	Pulse or Digital Communications	133	3.3
379	Telephonic Communications	111	2.7
128	Surgery (includes Class 600)	97	2.4
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	93	2.3
343	Communications: Radio Wave Antennas	60	1.5
520	Synthetic Resins or Natural Rubbers (includes Classes 520-528)	60	1.5
532	Organic Compounds (includes Classes 532-570)	57	1.4
	Total		43.3

Source: United States Patent and Trademark Office (2007).

Table 7: Top 10 Patent Classes by the Residents in Taiwan (China), 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
438	Semiconductor Device Manufacturing: Process	3,586	13.2
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	1,521	5.6
439	Electrical Connectors	1,496	5.5
361	Electricity: Electrical Systems and Devices	1,053	3.9
362	Illumination	645	2.4
81	Tools	445	1.6
280	Land Vehicles	382	1.4
365	Static Information Storage and Retrieval	357	1.3
345	Computer Graphics Processing and Selective Visual Display Systems	356	1.3
482	Exercise Devices	334	1.2
	Total		37.5

Source: United States Patent and Trademark Office (2007).

Table 8: Top 10 Patent Classes by the Residents in the Republic of Korea, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
438	Semiconductor Device Manufacturing: Process	2,363	11.8
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	1,104	5.5
365	Static Information Storage and Retrieval	1,000	5.0
349	Liquid Crystal Cells, Elements and Systems	861	4.3
313	Electric Lamp and Discharge Devices	521	2.6
370	Multiplex Communications	483	2.4
345	Computer Graphics Processing and Selective Visual Display Systems	477	2.4
455	Telecommunications	432	2.2
327	Miscellaneous Active Electrical Nonlinear Devices, Circuits, and Systems	394	2.0
369	Dynamic Information Storage or Retrieval	384	1.9
	Total		40.0

Source: United States Patent and Trademark Office (2007).

Table 9: Top 10 Patent Classes by the Residents in China, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
439	Electrical Connectors	269	17.0
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	106	6.7
361	Electricity: Electrical Systems and Devices	52	3.3
502	Catalyst, Solid Sorbent, or Support Therefor: Product or Process of Making	36	2.3
435	Chemistry: Molecular Biology and Microbiology	28	1.8
532	Organic Compounds (includes Classes 532-570)	28	1.8
520	Synthetic Resins or Natural Rubbers (includes Classes 520-528)	27	1.7
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	23	1.4
375	Pulse or Digital Communications	21	1.3
382	Image Analysis	21	1.3
	Total		38.5

Source: United States Patent and Trademark Office (2007).

Table 10: Top 10 Patent Classes by the Residents in Israel, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	334	6.5
128	Surgery (includes Class 600)	309	6.0
370	Multiplex Communications	202	3.9
375	Pulse or Digital Communications	140	2.7
382	Image Analysis	130	2.5
532	Organic Compounds (includes Classes 532-570)	125	2.4
435	Chemistry: Molecular Biology and Microbiology	116	2.3
250	Radiant Energy	109	2.1
606	Surgery (instruments)	109	2.1
385	Optical Waveguides	95	1.8
	Total		32.4

Source: United States Patent and Trademark Office (2007).

Table 11: Top 10 Patent Classes by the Residents in Brazil, 2001–05

Class	Class Title	Number of patents granted	Share of patent class (percent)
62	Refrigeration	30	5.8
424	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	19	3.7
417	Pumps	18	3.5
166	Wells (shafts or deep borings in the earth, e.g., for oil and gas)	13	2.5
532	Organic Compounds (includes Classes 532-570)	13	2.5
137	Fluid Handling	12	2.3
220	Receptacles	11	2.1
604	Surgery (Medicators and Receptors)	11	2.1
403	Joints and Connections	10	1.9
435	Chemistry: Molecular Biology and Microbiology	10	1.9
	Total		28.3

Source: United States Patent and Trademark Office (2007).

These data indicate that four of the most technologically dynamic smaller economies— Finland, Israel, the Republic of Korea, and Taiwan (China)—have fairly narrow capabilities, mainly in electronics/telecommunication components of various kinds and the life sciences. Limited as it is, this capability took more than 25 years to develop, and except in Israel, it resides mainly in a few multinational corporations that have production facilities and in some cases research laboratories all over the world. The areas of specialization are significant in three respects: they are in the throes of technological change; the nature of technologies in these areas prompts companies to undertake much patenting, sometimes of relatively minor advances for defensive reasons and for purposes of cross-licensing; and the codification of technology and its diffusion is fairly rapid, so that the rents from each generation of technology are quite short-lived.

Several inferences can be drawn from the experience of these countries that complement the lessons from the United States, Germany and Japan. One is that 25 years may be enough time to build technological capability in only a few areas. This capability may not be adequate to support the development of a regularly refreshed and diversified mix of products and services. A slowing of the tempo of change, unforeseen technological advances, or a migration of key researchers could quickly erode the narrow base of capabilities created.

A second inference is that the capability resides mainly in a small number of organizations whose headquarters and research facilities are located in a handful of major urban centers. Where these organizations are multinational corporations, their longer-term interests may not coincide with those of their current home country. In a globalizing world, it is all too possible to imagine companies moving their primary research activities and production facilities overseas. Were a Nokia or a Samsung to shift the bulk of its R&D overseas, the technological capability of Finland and the Republic of Korea could be seriously impaired, if not immediately, at least over time.

A third and related inference is that in Brazil, India, the Republic of Korea, and even Taiwan (China), research capability in the university sector remains limited; there are few institutional foci for cross-disciplinary research or intermediaries to promote the commercialization of applied research, although efforts to create them are now ongoing. Universities in these countries often lack the faculty, the recruiting policies, and the incentives to build balanced expertise across disciplines, including in the social sciences and the humanities or to motivate cross-disciplinary work. Additional funding cannot easily change staffing patterns, administrative and teaching responsibilities, departmental hierarchies, or promotion ladders. And even where larger budgets could help raise the salaries of university researchers, which are often low, recruiting staff at the appropriate levels, would be a complex undertaking. Attracting and retaining high-quality staff and building a fund of experience is a task that can span decades, even if there is a pool of national or international skills to tap.

Should China heed this experience? If so, how might doing so cause it to adapt its policies? Given China's size, its apparent success in mastering manufacturing technologies, and its growing supplies of science and technology personnel, the argument can be made that given a sufficiently large investment, China could achieve within another two decades what took the United States close to a century to put in place.

Accelerating Technological Advance

It might well be feasible to create sufficient technological capability within a decade to close the gap in selected areas of electronics, especially if multinational corporations from East Asia and other parts of the world continue shifting their production and research to China. However, even if the technology gap were closed, would China become a significant innovator in specific subfields? The experience of Japan suggests that catching up might be the easier part. Becoming a serial innovator is far more demanding.

The trends in innovation and the unpredictable nature of technological change argue for broad technological capability spanning many fields, similar to that of the United States. China has the size and industrial potential to achieve broad technological capability. Doing so, however, is certain to be time consuming, and the pace of progress is likely to be determined by the development of significant innovation oriented anchor firms in the corporate sector, as well as by basic and applied research at universities, research centers, and other institutions. These institutions will determine advances in knowledge, influence whether some of this knowledge leads to advances in technology, and intermediate the diffusion of this technology, particularly to smaller firms.

The extent to which a few corporations, universities, research centers, and individuals account for a high proportion of innovation says something about the quality of researchers. During the "catch-up" phase, having large numbers of science and technology personnel to assimilate technology from abroad may be an advantage. In contrast, innovation depends largely on the quality of the researchers, the size of the research teams, the research environment, the resources at their disposal, researchers' willingness to explore technological possibilities, and in many instances their readiness to engage in long-range basic research. In the life sciences and nanotechnology, where progress is rooted to advances in basic science, the architects of innovation are the star scientists who are experienced managers of research teams and institutes. These men and women lead and inspire others but also encourage debate and challenge current paradigms. Where new technologies are becoming more closely linked to not just basic science but also the enlightened concentration of inputs form several disciplines, the quality of the lead researchers and their ability to assemble cross-national and crosscultural teams takes on even greater significance.[14] Equally important is the readiness to focus not just on the fashionable fields but to look beyond at other promising areas. The inference is that the return from improvements in quality is rising fast. Trading quality for quantity might not be a good policy recipe, but quality is difficult to nurture, takes much longer, and is politically less rewarding than expanding tertiary enrollments or multiplying the number of research programs. Furthermore, the capacity and resources to cover diverse fields of enquiry, several in some depth, can be a major advantage.

Over the past 20 years, China has initiated a number of programs to promote technology development (Table 12). These programs and the many other initiatives relating to technology development constitute an impressive and sustained effort to build capacity. China's demonstrated ability to rapidly absorb foreign technology indicates that the programs are working.

At this juncture, there may no longer be a need for national programs to focus on the very basic quantitative indicators—such as the number of science and technology personnel, the number of papers published in major journals, the level of R&D, the number of patents issued—as these are growing robustly and may convey a misleading impression of innovativeness (Zhou and Leydesdorff 2006; Sigurdson 2005; WIPO 2006).[15] Instead, policy effort could now be brought to bear more forcefully on four specific areas. In conjunction with ongoing activities, focusing on these areas might make a larger contribution to helping China acquire the technological capability that undergirds an innovative economy.

- Promote R&D in larger corporations, Chinese and foreign, to prepare the ground for greater innovativeness, encourage global sourcing of research by the corporate sector, and spur the formation of research partnerships and consortia. This is ongoing with many foreign companies conducting R&D in China and coordinating this with their research (e.g. firms such as Microsoft, Novartis, Intel,

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[14] Judson (2005) examines the importance of growing a "scientific culture" in China, which can be a slow process. Cao (2004) cautions that China may not be able to realize its ambition of winning a Nobel Prize in science any time soon, because the gap between China and the West is still wide. Aizenman and Noy (2006) show that scientific leadership has lagged increases in GDP and is influenced by wars and immigration, particularly in the United States and Germany.

[15] China is emerging as a leader in the field of nanoscience, with a growing list of publications (Zhou and Leydesdorff).

Nokia, Google, SAP, etc.) elsewhere and Chinese firms such as Lenovo and Huawei.

Table 12: Major National Programs with Impact on University Research in China

Program	Agency	Year begun	Key focus
Spark	Ministry of Science and Technology	1985	Improve agricultural technology and develop agro-industrial clusters
Torch	Ministry of Science and Technology	1998	Develop high-tech industries and development zones and provide laboratories and equipment
863 (national high-technology research and development program)	Ministry of Science and Technology	March 1986	Enhance international competitiveness and improve overall capability of R&D in high technology (with 19 priorities)
National Key Technologies R&D Program	Ministry of Science and Technology	1982	Support applied R&D to meet critical technological needs in key sectors
973 (national basic research program)	Ministry of Science and Technology	June 1997 (combined with "Climbing" program, initiated in 1992)	Strengthen basic research in line with national strategic targets (primarily in agriculture, energy, information, resources and environment, population and health, and materials)
R&D Infrastructure and Facility Development	Ministry of Science and Technology	1984 (National Key Laboratories Program)	Support National Key Laboratories Development Program, National Key Science Projects Program, and National Engineering Technology Research Centers Development Program
National Natural Science Foundation	National Natural Science Foundation	1986	Promote and finance basic research and some applied research
211	Ministry of Education	1995	Improve overall institutional capacity and develop key disciplinary areas in selected universities, and develop public service system of higher education (three networks)
985	Ministry of Education	1998 (first phase); 2004 (second phase)	Turn China's top 150 universities into world-class research institutions

Source: Wu 2007; Sigurdson 2005.

- Enlarge the contribution of key universities to innovation, especially through a focus on basic research in a variety of scientific fields.
- Create and strengthen intermediary organizations that can help form alliances among firms; multiply formal and informal mechanisms of engagement between university researchers and firms; increase access to risk capital from venture

capitalists and angel investors; and facilitate the development and commercialization of research.

- Use urban policies to create the infrastructure and environment needed to germinate the social networks—local and international—that induce new knowledge creation, and maximize knowledge spillovers, including the exchange of tacit knowledge. Despite the shrinking of distance made possible by information technology, the geography of innovation remains highly location specific. Worldwide, probably no more than two dozen metropolitan areas attract and retain some of the most talented researchers and account for a disproportionate share of technological advances.

Promoting Research and Development

Increasing spending on R&D up to a certain threshold is necessary to build technological capacity. How much spending is needed to reach this threshold, how quickly it should be attained, and how far beyond the threshold spending should be pushed is uncertain.[16]

Fiscal incentives for R&D are widely used in industrial countries and have been introduced in China as well.[17] The weight of international empirical evidence suggests that they are effective in raising corporate spending on research.

The tax incentives currently being extended to firms in China are generous by international and East Asian standards. They include an exemption of up to 150 percent of R&D expenditure from corporate income tax and the provision of carry forward of any unutilized amount to offset tax liabilities up to four years in the future. Accelerated depreciation allowances permit firms to treat expenditures on equipment worth less than

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[16] Without a well crafted strategy and a coordinated approach to R&D and the commercialization of research outputs, R&D spending does not readily translate into profits (See Jaruzelski, Dehoff, and Bordia 2005).

[17] On the R&D tax credit, the voluminous body of research is essentially positive: the credit does stimulate R&D and increase welfare. However, the gains depend on (a) the design of the instrument (whether it is volume based or incremental [which affects deadweight losses], temporary or permanent, complicated or simple, subject to a cap; (b) the administrative burden imposed on companies by the claims process; and (c) the speed with which firms are reimbursed. A volume-based tax that has no cap, includes extra provisions for small and medium-size enterprises that are permanent, and is simple to claim is the most attractive, although it does entail higher deadweight losses (see Hall and van Reenen 1999; Bloom, Griffith, and van Reenen 2002; and Russo 2004).

Y300,000 as overhead; for more expensive equipment, the depreciation period can be shortened to as little as three years. High-tech start-ups pay no income tax for the first two years and 15 percent for the next three years (less than half the normal rate of 33 percent). The reduction can be applied for another three years if the firm remains classified as a high-tech enterprise. Companies that incur heavy expenditure on fixed investment as a part of their R&D activities will benefit from the switch to a consumption-type VAT.[18] Import duty exemptions on equipment for R&D purposes further augment earnings. Firms in the biotech, telecom, new materials, aeronautics, information technology, and electronics fields derive substantial benefits from such preferential tax treatment.

Tax incentives are complemented by direct central and subnational government spending on R&D. Grants by various ministries have reached significant levels and are rising faster than revenues. In addition, procurement policies of government agencies are designed to favor firms that are designated as innovative. This is especially helpful for firms in the telecoms, electronics, automotive, and customized software industries.

How, at this stage, might these policies be tailored to produce the best results? Increased spending on some activities classified for tax purposes as R&D might have low social returns, particularly where firms are still mainly in the assimilation stage and poorly equipped in terms of strategy, managerial expertise, organizational, design, and technical skills to conduct meaningful research or to use research findings for commercial purposes.

These constraints, especially the shortage of seasoned midlevel research managers, might argue for tax incentives that encourage the pooling of research effort by companies and a variety of alliances. The formation of research consortia might be one approach to favor. Joint programs with local or foreign universities might be another. Tax incentives could be made particularly generous for joint research programs with foreign companies, based on the scale of the foreign involvement and the subsector that is the focus of the research. This approach would encourage multinational corporations that

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[18] VAT rebates on semiconductors offered after June 2000 and amended in 2001 were ended in April 2005 (Sigurdson 2005).

already benefit from incentives to localize research activities to work more closely with Chinese firms.[19]

Incentives to offshore some research and engage more closely with researchers would recognize the realities of a globalizing research environment. This does not undermine the case for strengthening local capacity; it does argue for taking full advantage of international research and design capabilities where possible (as demonstrated by Brilliance Auto), in the interests of enhancing competitiveness. Offshoring research could put pressure on local research entities to improve their own performance; international research joint ventures can also be important vehicles for technology transfer. In short, as circumstances permit, the fiscally cost-effective approach to supporting corporate research at China's current stage of development might be one that stresses pooled effort locally and globally. This approach would recognize that in certain cases it may be more efficient to allow Chinese researchers to continue working abroad rather than offering them generous incentives to return,[20] only to find what could be initially a less productive niche in the local research environment.[21] The approach

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[19] The contribution of research consortia in Japan has been described by Branstetter and Sakakibara (1998; 2002). Such consortia have also been created in the Republic of Korea and the United States (see Sakakibara and Branstetter 2003; Sakakibara and Cho 2002). Although the results are not as compelling with regard to the role of foreign firms in China, Whalley and Xin (2006) find that foreign companies and joint ventures that on balance were more capital-, technology-, and skill intensive were responsible for nearly 60 percent of exports and close to 40 percent of China's growth in 2003–04. They were also responsible for almost half of all patent applications to China's patent agency in 2005 and nearly two-thirds of all patents granted (WIPO 2006).

[20] The Chinese government provides financing for researchers willing to return to China to work for up to one year in areas outside their selected fields. These activities include joining research programs sponsored by the state, ministries, or provincial governments; helping domestic institutions solve key scientific issues; and giving lectures and conducting training, attending international conferences or important national meetings, and assisting in technology transfer and technical exchanges. The sponsorship consists of international travel and living allowances. The *Chunhui* program has sponsored 8,000 Chinese scholars with PhD degrees obtained overseas who returned to China to carry out short-term work. The Yangtze River Fellowship program awarded 537 overseas Chinese scholars appointments in Chinese universities for curriculum building, teaching, and joint academic research. China also established overseas student business bases or industrial parks, organized jointly by the central and provincial governments to help returned overseas students start up businesses in China. The central and provincial governments share the expenses of building infrastructure and other facilities and providing services as required for business environment (http://www.moe.gov.cn; http://www.mop.gov.cn).

[21] Of the 300 scientists of Chinese origin who are recognized as leaders in their fields, only 5 have returned to China (Cao). While the research environment in China is changing, seniority is a paramount criterion in decision making, and junior scientists are often unwilling to challenge their mentors or elders, according to Cao.

would also benefit from a further strengthening of the institutions protecting intellectual property, especially the courts.

Are new firms a significant source of technology advances? The evidence is stronger for the biotech, software, and telecom/electronic components subsectors than for others, and much of the evidence comes from the United States. Fewer data from East and South Asian economies support this position. In India, Japan, the Republic of Korea, and other Asian countries, larger firms are clearly more innovative than smaller ones. Nevertheless, a scheme comparable to the Small Business Innovation Research program in the United States, which targets firms with promising technologies, could increase the flow of innovation from smaller firms by supplementing the venture capital that is already available from government sources and the private sector.

Supporting Universities and Creating Linkages with Businesses

Although the primary locus of technology development and innovation is generally the business sector, the building of capability hinges on the talent produced by and the mix of research conducted at universities. The leading Western and Japanese universities, a few of which are at the forefront of science and technology development, went through a lengthy gestation period, during which they devised, tested, and refined curricula and pedagogic techniques and established reputations as centers of excellence for higher education. Among these larger universities, many have strengthened their research activities, but the best still view their primary mission as imparting a first-rate education in order to prepare the researchers and knowledge workers who will take up the challenge of science and technology development.

For Chinese universities, which are engaged in an extraordinarily rapid expansion in enrollment, the issue of quality is central, especially for the leading ones.[22] All Chinese universities are adding to their faculties, to the variety of courses they offer, and to their physical infrastructure. Some are also entering into or enlarging the scope of their research. The hierarchical social organization of many departments, which often defines the content of teaching and research, is a major issue. Recruiting a sufficiently diverse

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[22] China had more than 1,000 colleges and universities in 2004, several hundred of which offered graduate courses. Total enrollment was 14 million. The target for 2010 is enrollment of 30 million (Sigurdson 2005).

junior faculty, from across the country and overseas, with the requisite expertise and skills and bringing them up to speed is a second. Striking an appropriate balance between teaching and research is a third. It may be a decade or more before these issues are satisfactorily resolved. During this period, and possibly beyond, it would be desirable to proceed cautiously with applied research programs aimed at developing commercial technologies and establishing linkages with the business sector. While the leading U.S. universities often conduct research that is a precursor of commercial technologies and university researchers collaborate with their corporate counterparts, even the likes of MIT, Stanford, and the Universities of California are responsible for only a tiny percentage of total patents and spin-offs, and companies in the United Kingdom and the United States give a low ranking to contacts with universities as a source of commercial innovations (Hughes 2007; Lester 2005). Net income from licensing, royalties, and spin-offs represents just a small fraction of the research budgets of these universities (Mowery 2007).

By some measures, Chinese universities have edged past their U.S. counterparts in terms of university-affiliated spin-offs. In 2004, the 600 leading universities had more than 4,500 affiliated companies, close to half of which were described as technology intensive. A large percentage of these enterprises were created to provide jobs to university staff who cannot be laid off, however, and do not represent genuine high-tech spin-offs. Universities such as Tsinghua and Beijing apparently derive sizable revenues from these business activities, but whether most universities are likely to benefit from becoming business conglomerates is uncertain. If they become less specialized and are diverted from their core mission, there is a risk that the quality of both teaching and research could suffer over time (Dasgupta and David 1994). This dilution of core competence is frequently the case in industrial conglomerates when diversification strains managerial and organizational capacities.

Hence, at least over the course of the next decade, fiscal incentives and budgetary support could help universities move through the transition phase; build the capability for providing a good-quality education that develops creativity; and strengthen the ability of the leading universities to pursue basic research in novel directions. The larger universities need to be encouraged to pursue links with business firms, but commercial objectives should not overshadow those of teaching and research.

Establishing Channels for Focusing Research and Diffusing Research Findings

A consistent finding of many studies of technological development is that research conducted at universities and institutes diffuses slowly to the business sector, and only a small fraction of this knowledge is ever commercialized.[23] The main beneficiaries are large corporations engaged in in-house research, which are more likely to be seeking new technologies, commissioning new work, and licensing it. Small and medium-size enterprises benefit far less, because of lack of preparedness or in-house absorptive capacity, lack of awareness of research being conducted by universities, and the inability or unwillingness to incur the transaction costs of licensing patents or harnessing researchers through consulting contracts or other vehicles for cooperation (Boschma 2005; Kodama and Suzuki forthcoming).

To remedy this diffusion failure, national and subnational governments and business associations have crafted mechanisms for creating institutional or organizational channels for focusing research efforts and diffusing research findings, especially to small and medium-size enterprises. The purpose of these initiatives, of which there are numerous examples in North America, Europe, and Asia, is to provide resources for priority technologies, to establish networks of firms to circulate new knowledge, and to mobilize the research assets of the region and use them more effectively. In the United Kingdom, for example, Research Council Centers, Regional Development Agencies, and Faraday Partnerships provide such services. The University of California-San Diego's CONNECT program brokers relationships between business firms and researchers. Such midwifery is performed by TEKES (the principal agency funding and promoting technology) in Finland and by state agencies in India (Basant and Chandra forthcoming).

A somewhat different but equally valuable input is provided by venture capitalists and experienced angel investors. In the United States, angel investors are far more important than venture capitalists for early-stage financing ("Giving Ideas Wings" 2006;

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[23] Adams, Clemmons, and Stephan (2006) review the literature on diffusion from universities and estimate that the modal lag period is more than three years.

Branscomb 2004) the two sources of capital are essentially complements. Experience suggests that experienced venture capitalists and angel investors with deep knowledge of an industry, organizational skills, local knowledge, and many contacts, local and foreign, are the most useful. Accumulating such human capital is a function of business successes and time, as well as the overall urban environment, including the social environment.

Creating Urban Centers that Attract Innovation Activities

Innovative activities are largely urban phenomena, localized in relatively few urban regions (Hall 2001; Markusen and others 2001; Florida 2002). These centers, which host some of the world's leading universities and research institutes, have attracted major anchor firms and have well-developed sources of finance, including sources of risk capital. The presence of successful universities, dynamic firms, and multiple sources of finance is closely related to urban development strategies that have helped create a physical and social environment that is conducive to innovation.

Physical location and history are often important (as in the cases of Boston or the San Francisco Bay Area, for instance), but the maintenance of an urban comparative advantage based on technology requires sustained investment in infrastructure, services, and institutions. Such development depends on the leadership, fiscal resources, organizational skills, and policies of municipal governments, conducted within a framework defined by the national authorities. Such a national framework and local development initiatives have broader aims than simply stimulating technological innovation, but building technological capacity can become a major component of central and subnational policies. The central government can promote localized technological capability through intergovernmental fiscal measures; targeted research grants; support for specific public universities and research institutes; funding for science parks; and infrastructure development that pulls in industry and institutions such as those buttressing intellectual property that encourage innovation.

Municipal governments can reinforce these measures and research, as subnational governments in the United States have done (Jenkins, Leicht, and Wendt 2006). Municipalities also play an important role in the creation of science parks, often adjacent to research centers, as well in land use policies, which determine housing and commercial development. From the perspective of technological innovation in a globalizing environment, arguably the most important municipal-level actions with significant long-term fiscal implications are the provision of high-quality public services, social amenities, urban transport, and an information technology system, which together with efficient regulations influence the attractiveness of an urban center for knowledge-based activities. Maintaining and progressively modernizing such services and such infrastructure involves a high level of current expenditures. The ability to mobilize the needed revenue depends on the elasticity of the local tax system; the adequacy of charges and fees for services; the effective division of labor between public and private providers; and strong governance, in particular the harnessing of e-governance.

In China, Shanghai, Beijing, Shenzhen, Guangzhou, Chengdu, and Xian are among the urban centers that are taking the lead in building urban innovation capability. In both Shanghai and Beijing, central and municipal authorities are investing heavily in physical infrastructure and services, including science parks and university R&D (Sigurdson 2005). The challenge ahead for these and other cities is to achieve and sustain a high level of public services. Shanghai, Beijing, Xian, and other cities also need to substantially improve their social amenities, particularly recreational amenities and the quality of the environment, which remain weak points. Improvements along these lines will help attract and retain talented people and dynamic firms.

If the recent geographical patterns of technological innovation persist, most advances in technology will be concentrated in a small number of urban centers. The development strategies of China's leading cities will thus influence the growth and distribution of research capabilities, the location decisions of anchor firms, and the emergence of links between firms and research institutions.

A Brief Summing Up

China is determined to achieve technological parity with the front running economies and to do so within the next decade or two. Its R&D effort are deployed across a broad front ranging from automotive and electronic technologies to high energy physics, to space exploration, nuclear energy and consumer product design. The government is allocating large sums to research and providing generous incentives to private firms, domestic and foreign. But as international experience clearly demonstrates, financing is only one factor albeit an important one. The productivity of an innovation system depends also on the volume of talent, and depth, as well as the heterogeneity of experience. Cross country studies show that the creativity of talented people is stimulated by society and how companies maximize the commercial benefits from R&D through effective strategies, management and coordination of research, production, and marketing.

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