The giant graduates: China's strive for high-technology

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While China's tremendous growth performance and catching-up process over the last few decades are undisputed, opinions on the sustainability of its economic growth could not be more diverse. On the one hand, analysts extrapolate the current growth performance and foresee world leadership within the next 20 years; others point to China's lack of innovative capacity and expect the leveling out of the current growth dynamic as soon as China's immense supply of cheap labor is absorbed and the potential for factor-driven growth recedes.

Overall, the debate appears highly politicized and to a large extent emotionalized, as the Western world fears the emergence of a new (authoritarian) economic superpower in the Far-East that will inevitably alter the global industrial landscape and the competitiveness of countries across the world. And while the advanced industrial countries are still struggling with the structural consequences of China's entry into the world market as a major supplier of labor-intensive products such as textiles and shoes, the country has long embarked on a far more ambitious development trajectory aiming for technological leadership.

This paper seeks to complement the ongoing debate by shedding some light on China's technological development path. While a comprehensive analysis of China's technology policy would be well beyond the scope of this contribution, I will compile selected policy priorities that may serve as indicators of China's future development path. For this purpose I will follow the common notion of endogenous growth theory that the creation of new technologies and knowledge is not exogenous, but explainable by discrete input factors. In particular, my brief analysis will focus on investments in research & development (R&D) (Romer 1986) and the development of the human capital stock (Lucas 1988; Romer 1990) as major determinants of national growth trajectories. The paper will proceed in four sections. The first section gives a brief overview of China's efforts to create a national innovation system; section two focuses on the role of human capital development and section three sheds light on supporting policies. The last section concludes.

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National technology programs

Following its socialist planning tradition, the Chinese government developed a technology policy that basically relies on central planning and resource allocation. Major institutions in charge of formulating the national Science & Technology (S&T) plans are the State Science and Technology Commission and the State Economic and Trade Commission.

Science and technology programs are a focus of policy

Four mutually complementary S&T programs constitute the framework of China's national technology policy. Each of the programs supports a close science-business interface in order to secure innovation activities with good prospects for productivity growth and to maximize the commercialization of R&D output. While the individual programs follow a set of distinct core objectives and usually favor specific tools to enhance technological development, the planning institutions gradually adjust the detailed plan priorities and favored research topics in response to changing overall national development goals.

The "Key Technologies R&D Program", implemented as early as 1982, was designed to support specific key projects within the scope of national priority sectors. The program provides advanced applicable new technologies, materials, techniques, and equipment in order to speed up the national modernization process in key industries. Another goal is the development of a national research elite involved in key technology R&D. A central concern is the research-business interface and the support of joint projects between universities, research institutes and enterprises. The core principle of the program is to establish the firm as the major venue of innovative activities. The "Spark Program" was implemented in 1986 to speed up the development and technological upgrading of China's rural areas. In particular, the program is aimed at the acquisition of S&T inputs by China's rural, predominantly labor-intensive township-village enterprises (TVEs). Main beneficiaries of the program were the less developed TVEs in China's inland provinces. "Program 863", also implemented in 1986, reinforces the role of education and human resource development. A major tool of the program is the funding of international co-operations. Current research priorities include the development of the telecommunication sector, key biological, agricultural and pharmaceutical technologies, research on new materials and advanced manufacturing technologies and the advancement of key technologies for environmental protection, resources and energy development. Finally the "Torch-Program", launched in 1988, focuses on the development and provision of a high quality research infrastructure and a beneficial innovation climate. The program provides facilities, encourages the funding by banks or state-owned enterprises, and develops management skills among technical personnel. Through the clustering of technology-rich enterprises in technology zones, the program seeks to create synergies across key industries. Successful examples of companies that developed under the Torch Program are "Legend Computers" and "Founder" (a producer of typesetting software).

High-tech areas need a high quality research infrastructure

State-guided R&D acquisitions bear the inherent risk of selection problems and collusion, however. The risk of resource misallocation may be even more pronounced in non-democratic regimes that are characterized to a larger extent by objectives of prestige with a strong signaling effect to the international community. In an effort to alleviate the risk of misallocation, the government's *"Decision on the reform of the science and technology management system"* (1985) called for decentralization and a reduction of government competencies in the choice and selection of research proprieties, breaking the close links between government and R&D facilities, and more intensive competition in the field of R&D policy. The procedure of planned allocation of S&T funds was replaced by public competitions, and the potential for the commercialization of S&T output emerged as a major criterion for funding decisions.

Concurrent with the structural changes within China's research landscape, the central government has gradually increased the relative role of R&D policies. In 1995, the *"Decision on accelerating scientific and technological progress"* formulated a target value of 1.5 percent of GDP for national S&T expenditures. While China has not yet reached its target, the development of R&D expenditures during the last few years is indeed impressive. Between 1999 and 2003, annual R&D expenditures increased from 0.8 percent to 1.3 percent of GDP, meanwhile surpassing even the average value of the EU-15 countries. The majority of R&D expenditures accrue in the business sector, followed by R&D institutes and universities. In parallel, the proportion of scientists and engineers in the overall S&T population increased significantly from 54 percent to 69 percent between 1999 and 2003 (State Statistical Bureau 2004).

Human capital development

The crucial role of human capital as a determinant of national growth is undisputed. Countries with a larger supply of human capital tend to grow faster, while too little human capital can have a constraining effect and explain why some of the poorest countries do not grow at all (Romer 1990). Even countries with a large labor force, such as China, will eventually suffer from low growth rates. Particularly the recent growth performance of NICs such as Taiwan, Korea and Singapore, countries of the so-called East Asian miracle, supports the importance of human capital formation within national growth strategies (Nelson and Pack 1999).

The positive growth effects of human capital are generated through diverse mechanisms. First of all, education increases the skill levels of workers and thereby raises productivity. In addition, education improves the adaptability of individuals. Structural changes and reallocation processes towards more efficient usage of scarce resources are facilitated by increasing the individual mobility of workers across sectors and industries. In a more general sense, education enhances the ability to detect and realize new profit opportunities in a highly dynamic business environment. Without high rates of investment in human capital and a sufficient supply of well-trained managers, scientists and engineers, new profit opportunities would easily be missed. This aspect is particularly crucial for transition economies undergoing major liberalization processes and subsequent structural changes in their economies. Finally, people with higher levels of education will be better equipped to manage the transfer and implementation of advanced technologies, new ideas, modern management techniques, international standards and business practices. In short, national innovation systems focusing purely on the promotion of R&D activities may produce few effects if the stock of human capital remains underdeveloped.

China's leadership has understood the multiple effects of human capital formation and the need for an educated and skilled workforce, having emphasized the role of education – particularly higher education – since the mid-1990s. Overall financing of education increased from 2.8 percent of GDP in 1991 to 5.2 percent in 2002. Government funding equaled 3.3 percent of GDP in 2002, while the remaining educational funds were generated by tuition fees and non-government funding organizations (State Statistical Bureau 2004). In terms of public expenditure on education as a percentage of GDP, China is meanwhile comparable with Singapore and ranks only slightly below Japan and Korea. Institutions of higher education enjoy special attention, receiving 23 percent of government appropriations for education in 2002.

In a national effort to increase the quality of human capital, the major universities provide generous compensation packages to attract faculty from elite Western universities either for long-term positions or visiting and joint appointments. At the same time, the capacities of institutions of higher education have been extended by a large margin. Student enrollment increased from only 0.9 million at the outset of the reforms in 1978 to more than 11 million in 2003. Over the last decade, the number of university graduates has more than doubled, reaching approximately 1.9 million p.a. today. Due to China's centralized system of university entry exams, the structural composition of university graduates is closely aligned with the specific needs of China's economic development. About 35 percent of China's university graduates hold a degree in engineering, 15 percent in business administration and another 9 percent in natural sciences (State Statistical Bureau 2004). This makes China the worldwide biggest producer of engineers (in absolute numbers) along with the United States.

China is also eager to extend international agreements on student exchange in order to benefit from foreign programs in higher education. In 2003, approximately 120,000 Chinese students were enrolled in universities abroad. To increase the return-rate of students, government institutions offer research positions and funding for returning junior faculty members. The Chinese National Natural Science Foundation (NNSF), for instance, provides research opportunities and resources for junior university faculty and facilitates collaboration with scientists affiliated with the Chinese Academy of Sciences.

Finally, China's development benefits from a widespread hunger for education. Self-learning and evening classes are popular among China's ambitious young professionals, who are eager to move up the career ladder and wish to have a stake in China's economic development. The market for economic publications and translations of Western standard literature in engineering, natural science and economics testifies to the great interest in learning and human capital accumulation. In 2003, the shares of publications in the field of industrial technology and economics were as high as 12 percent and 8 percent, respectively, of China's total book publications, whereas ideological works (Marxist-Leninism and Mao Zedong thought) were down to an all time low of 0.3 percent (State Statistical Bureau 2004). Interviews with entrepreneurs support the general observation that China's urban professional classes pay utmost attention to the role of human capital development as a major determinant of their economic success.

A national effort to increase the quality of human capital

A supportive business environment

While the state may play a crucial role through direct budget appropriations for R&D and the education sector, China's technological catching-up process benefits equally from indirect mechanisms triggered by individual economic actors.

The emergence of a national entrepreneurial class

The locus of innovation is the firm. That is, without a thriving business sector responding to competitive pressure, national technology programs would eventually have only small effects. China's fiscal decentralization move in the early 1980s appears to be a strong driving force for the creation of a positive business environment. China's policy of fiscal decentralization has constituted a key institutional innovation aimed at strengthening the economic incentives of municipal and provincial governments to support market-oriented economic reform. According to the fiscal revenue-sharing system, lower-level governments have the obligation to submit a fixed proportion of fiscal revenues to their superior government unit, while retaining the rest for their own budgets. Given that tax revenues are positively correlated with firms' performance, bureaucrats have an incentive to do what they can to assure that local firms prosper (Montinola et al. 1995; Li 1998). In addition, many municipalities implement individual incentive schemes to align the interests of bureaucrats with local economic objectives. Hangzhou city, for instance, a municipality in the Yangzi Delta, rewards bureaucrats with a bonus payment equaling 1 percent of the total volume of new investment contracts.

As a result, the local business environment in China improved significantly over the last decade. A thriving private economy with a large proportion of small and medium-size firms has developed, ready to serve as a major engine of innovation and productivity growth. Intensive competition and low entry barriers reinforce the role of innovation. Firms often benefit from close university-business ties. Particularly in China's new high-tech industries, university-business collaboration in R&D and knowledge transfers play a crucial role, with many high-tech start-ups being university spin-off companies. The development of a supportive university-business interface is driven by a close alignment of the individual incentive structures of entrepreneurs and scientists. While entrepreneurs need to develop their innovative performance in order to survive in China's highly competitive market environment, marked by strong competition by international firms and small and medium-size national firms, scientists are often driven by material concerns. Due to the unfavorable wage structure in the institutions of higher education, scientists are eager to start up their own businesses or to work as consultants for the business sector. Consulting honorariums of up to 95 percent of total personal incomes are not exceptional for knowledgeable and ambitious faculty members.

Firms benefit from close ties with universities

Learning from abroad

In contrast to Japan's technological catching-up process, which basically relied on the country's national development strength, China's reformers embraced foreign technology to jump-start national economic development. Foreign direct investment (FDI) emerged as a core element of the national reform agenda from the outset of economic reforms in the late 1970s. FDI was promoted to serve two complementary purposes: First of all, it obviously alleviated China's capital constraint; secondly, the new FDI policies were specifically designed to speed up the country's technological catching-up process through channels such as reverse engineering, skilled labor turnover, and demonstration effects. The establishment of special economic zones with generous tax incentives not only facilitated the inflow of scarce capital, they also served as entry ports for advanced technologies, western-style management techniques and organizational blueprints. The concept of preferential FDI policies quickly spread and the country-wide development of technology parks and development zones facilitated an immense inflow of FDI across the whole country. Meanwhile, China ranks number one worldwide among FDI recipient countries with an FDI inflow of $115 billion in 2003 (State Statistical Bureau 2004). Not only the volume of capital inflows gives credit to the planners' strategy; in response to specific investment incentive schemes, FDI gradually shifted from labor-intensive technologies towards capital and know-how intensive technologies, thereby mitigating the country's technological backwardness. Local content regulations guaranteed that national firms benefited from the growing FDI inflow as suppliers of inputs and machinery. More recently, local content regulations have even included R&D activities in order to deepen the technological exchange between multinational corporations and local firms. Multinational corporations are increasingly forced into research co-operations with local research laboratories and university institutes if they want to gain market access. And none of the big multinationals like General Electric, Microsoft, IBM, Motorola or Siemens is willing to miss its chances. The deal is as clear as it could be: The Chinese are trading market access for technology.

Endogenous growth theory supports the idea that FDI may increase the efficiency of potential national innovators through the indirect transfer of knowledge. FDI provides a stimulus for national research activities, as knowledge is never appropriated solely by one firm, but will always create new production and research possibilities for other firms. As Romer (1990) points out: "If an inventor has a patented design for widgets, no one can make or sell widgets without the agreement of the inventor. On the other hand, other inventors are free to spend time studying the patent application for the widget and learn knowledge that helps in the design of a wodget". This observation describes very well the research approach of many Chinese entrepreneurs, who often rely on reverse engineering and further development of western technology imports. Examples abound: Based on the core technology supplied by its German partner, the refrigerator company Haier became a pioneer in developing high-efficiency, chlorofluorocarbon-free refrigerators. Similarly, design and development centers of China's automobile factories draw heavily on technology imported by their Western joint venture partners. Jinliang Motors, for instance, just recently secured the first export contracts to Europe with their model "Landwind," a hybrid constructed with a Mitsubishi motor and a car body resembling General Motor's "Frontera." The Little Swan Group Company increased its own innovation capacity with an initial technology transfer from Matsushita, the Japanese producer of washing machine components, which served as a catalyst for in-house development of further product innovations (Pech et al. 2005). In support of these cursory observations, Cheung and Ling (2004) offer empirical evidence of positive spillover effects of FDI on innovation in China.

Selected Industrial Products, 1995 to 2003

	Household refrigerators (million)	Air-conditioners (million)	Micro-Computer (million)	Integrated Circuits (billion)
1995	9.18	6.82	0.83	5.52
1996	9.79	7.86	1.39	3.89
1997	10.44	9.74	2.07	2.55
1998	10.60	11.57	2.91	2.63
1999	12.10	13.38	4.05	4.15
2000	12.79	18.27	6.72	5.88
2001	13.51	23.33	8.78	6.36
2002	15.99	31.35	14.63	9.63
2003	22.53	48.21	32.16	14.83

Source: State Statistical Bureau (2004).

Taking stock

China's recent technological catching-up process is impressive. A team at the Beijing Genomics Institute was the first to decode the rice genome, national vendors of network switches, Huawei Technologies Co. and ZTE Corp., managed to snatch contracts from the Cisco Systems and Nortel Networks, and China has been successfully launching satellites for years now.

The national production of higher value-added products has increased dramatically during the last few years, though the starting levels were admittedly low (see Table). Exports of China's high technology industries increased from $13 billion in 1995 to $110.4 billion in 2003, accounting for about 25 percent of total exports and clearly surpassing the high-tech share in Germany's exports of about 18 percent. Patenting also developed dramatically with only about 100,000 patents granted in 1999 and more than 180,000 patents granted in 2003. While direct causal links between technology policies and innovation performance are hard to establish, the evidence supports the conclusion that China's recent moves in innovation and education policies provide fertile grounds for the country's technological catching-up process.

Nonetheless, the country still has far to go to become a high-tech superpower. High-tech production is not yet "Chinese", as Sino-foreign joint ventures contribute more than 50 percent to China's total high-tech exports. But the rapid development over the last few years sends a clear signal that China is striving to be more than the world's biggest socks-and-buttons producer. China, where gun powder, the compass and paper were invented, is steadily moving up the production chain, claiming a growing market share of global high value-added products and preparing to reclaim its past technological supremacy.

Chinese firms rely on the further development of imported technology

Of course, China won't become a technological superpower this year or next. And there are still several risks along the way. Upcoming reforms of the banking and financial sectors will pose critical economic risks that may easily reduce China's short-term growth perspectives. Political stability needs to be secured, and will increasingly depend on the leadership's ability to deal with rising social instability as a consequence of widening income gaps and regional development disparities. But after reviewing China's determined catching-up performance since the end of the Cultural Revolution, who would actually doubt that China will achieve its ambitious goals? Doubts are better founded as to whether the West will be prepared to accept the challenge.

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