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People's Republic of China's Technological Capability

Jon Sigurdson, Stockholm School of Entrepreneurship

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By Jon Sigurdson, Stockholm School of Entrepreneurship

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Table of contents

Introduction[1]

The People's Republic of China (PRC) is now seen as the engine of economic growth in our global system. Let me start my referring to comments made by one of our leading development economists, almost to the date 25 years ago. Sir Arthur Lewis, the Nobel Economics Prize winner in his lecture to the memory of Alfred Nobel on December 8, 1979 gave the following title to his speech: **The Slowing Down of the Engine of Growth**. He started his talk with the following sentences.

> Let me begin by stating my problem. For the past hundred years the rate of growth of output in the developing world has depended on the rate of growth of output in the developed world. When the developed grow fast the developing grow fast, and when the developed slow down, the developing slow down. Is this linkage inevitable? More specifically, the world has just gone through two decades of unprecedented growth, with world trade growing twice as fast as ever before, at about eight per cent per annum in real terms, compared with 0.9 per cent between 1913 and 1939, and less than four per cent per annum between 1873 and 1913. During these prosperous decades the LDCs have demonstrated their capacity to increase their total output at six per cent per annum, and have indeed adopted six per cent as the minimum average target for LDCs as a whole. But what is to happen if the MDCs return to their former growth rates, and raise their trade at only four per cent per annum: is it inevitable that the growth of the LDCs will also fall significantly below their target?

In his speech did Arthur Lewis on no occasion mention PRC that in the following couple of decades has achieved a tremendous high rate of economic growth. PRC's experience is analogous to similar rates of growth in Japan, the Republic of Korea and Taipei,China. It is similar to the experience of those countries in that PRC's recent economic growth was initially export-led and overseas demand for industrial products continues to play an important role. However the export-led growth is now being complimented or even replaced by the growth of the domestic market, the size of which has no parallel in the earlier development in neighbouring countries. PRC has not only primed its own engine of growth after several earlier false starts in economic development. The country has also created a great impact on almost every other country in the world that now has to react to challenges of competition and collaboration.

Furthermore PRC is in its future industrial technological development basing itself on a combination of three important knowledge sources that will define its future technological capability. First, PRC is expanding its funding of R&D that far exceeds its rate of economic growth although much of those resources are used within a national innovation system that is suffering from an hangover of the earlier planned economy period. Second, the country has through its Open-Door Policy attracted a huge amount of foreign direct investment in which manufacturing has played an important role, now increasingly followed by FDI in R&D. Triggering this development is the importance of

[1] The views and facts reflect ongoing research on Asian developments in science and technology, now carried out as Visiting Research Fellow at the East Asian Institute, National University of Singapore. Results will be incorporated in a forthcoming book – tentative title: China Technological Superpower – that will be published by Edgar Elgar (UK) in 2005.

the size and sophistication of the Chinese market combined with the talent pool that is being created for which the universities will play an important role. Third, Chinese companies are beginning to critically invest in R&D, with the medium-term ambition to become leading global companies.

This paper will exemplify PRC's ambitions, strategies and results in selected industrial sectors. Textile is an example of a traditional industry where PRC has established a strong competitive advantage not only because of its low labour costs but also by significant technological upgrading. Technology plays an even more important role in sectors such electronics. Here PRC started with an emphasis on consumer electronics at the lower and is now following through with a strong entry into integrated circuits at the higher end. Aircraft and supercomputer industries are provided as illustrations of sectors where the future size of the domestic market – similar to electronics – could have a strong bearing on the outcome, and where PRC already has established a strong position as a component maker for Boeing and Airbus. Finally, biotechnology will be mentioned as an example where PRC, being less of a latecomer, has decided to join the world league nations in a research domain that has great future potential.

Technological Base and Changing Trade Patterns

Textiles

The 1995 trade pact, Agreement on Textiles and Clothing will come to end by 2004. The members of World Trade Organization that signed that agreement have agreed to end the quotas that for the last ten years have strongly regulated global trade in textiles and clothing. The prediction is that American and European companies that currently buy from about 60 countries might source from as few as 20 by 2006 and less than 10 by 2010.[2] Expectation is that PRC might capture some 50 per cent of the trade compared with presently 16 per cent. To reach this level of dominance Chinese manufacturers might lower prices as many of them already run very efficient operations[3]. Many Chinese companies are already offering improved supply-chain management and value-added services in design, with the following illustration from Luen Thai which is the largest apparel maker listed on the Hong Kong Stock Exchange[4].

> At the Dongguan compound, Luen Thai provides major clients such as Polo Ralph Lauren and U.S. department-store chain Dillard's with dedicated teams of designers, merchandisers and sales staff – all housed in plush offices located on the factory site. Keeping designers close to production cuts development time and improves communication. Luen Thai teams are also able to learn about client expectations for materials, styles and costs. Eager to please, the company even bought a roomful of washing machines so it could carry out product testing previously farmed out to a laboratory in Hong Kong, China. There are top-loading

[2] Gida, Aravid, Hanging by a thread – Textile factories throughout Asia face extinction as a long-standing global trade pact is to expire, Time November 1, 2004

[3] A Time report refers to data compiled in an International Monetary Fund working paper that provides the following information. "The average Chinese garment worker was paid $1,600 in 2001, more than double his Indian counterpart's salary and four times what he'd make in Bangladesh. Despite the Chinese worker's higher pay, the study found his productivity was significantly higher: he adds $5,000 a year in value to the garments he processes, compared with $2,600 by his Indian equivalent and $900 by a Bangladeshi worker. The difference reflects PRC's greater investment in modern manufacturing equipment and in infrastructure such as transportation." (Ibid.)

[4] Ibid.

Sanyo washing machines for clothes bound for Japan, Zanussis for Adidas-brand sportswear and outsize Kenmores for the U.S.

The looming drastic changes in global trade pattern for textiles and garments have triggered the US to protect its remaining garment industry[5]. PRC agreed when it joined WTO to let the US and other countries impose emergency restrictions on its textile imports until the end of 2008. Thus a WTO member state can continue to limit textile imports from PRC on the ground that they may cause “market disruptions”. The US administration during late October and early November launched altogether seven investigations that could lead to import restrictions for clothing and textiles from PRC, including cotton pants, underwear and knit shirts.

Electronics

Moving up the Technological Ladder – Standards as Competitive Tools

PRC news media on October 22 2004 reported that “the number of mobile phones supporting multimedia applications will reach 380 million and the size of the mobile phone industry will reach US$76 billion by 2007 globally[6]. The same source mentioned that mobile communication multimedia represented by 3G service is expected to enter into vigorous development: “By 2008, the global market size of mobile game services, mobile photo services, mobile colour message services, mobile short message services and other existing services will reach US$17.5 billion, US$44 billion, US$60 billion, US$25.2 billion and US$8 billion respectively, which represents a great market potential for players in this field.”

To meet this challenge nine leading Chinese telecom institutions have formed the mobile multimedia technology alliance (MMTA) with the objective of making industrial alliances that could bring breakthroughs in the development of PRC's booming IT sector - backed by the government. Included in the MMTA alliance are telecom operators - China Mobile, China Unicom, China Telecom and China Netcom, and equipment providers - Huawei Technologies, ZTE Corporation, Putian Corp and Vimicro Corporation. MMTA also includes a research institution - the China Academy of Telecommunication Research of the Ministry of Information Industry (MII.

The alliance has been set up to boost technical innovation and development of standards and applications in a booming mobile multimedia industry[7]. "The purpose of MMTA is to integrate the forces of various players in the value chain of the mobile multimedia industry to promote the innovation and standardization of networks, terminals and applications," according to MMTA president - Jiang Lintao. A more general purpose is to boost the competitiveness of Chinese enterprises in the race to apply upcoming 3G (third generation) technologies.

The alliance will include software developers and Internet content providers in addition research institutions, operators, terminal and network equipment manufacturers and

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[5] US curbs loom for Chinese textile industry –Seventh probe under way, on fears of job losses when cheap imports flood the US market. The Straits Times, November 20, 2004

[6] Industrial alliance boosts IT sector, http://www.chinamet.com.cn/english/MEspecial/invest/invest-envo-detail.jsp?id=1890

[7] Zhang Xinsheng, deputy director of MII's science and technology department

core chip technology providers. "But Chinese firms need to co-operate if they want to grab a larger market share facing the stiff competition from international rivals[8]," Foreign partners will be allowed to join, but rules will be quite different from those of domestic members.[9], and a detailed rule will be rolled out in coming months.

The MMTA example mentioned above is only the tip of an iceberg of PRC's effort to climb the technological ladder. PRC's industrial development that fuelled its success in exports has been based on Chinese abundant labor offered at low cost to foreign investors as well as domestic companies. Many and soon most of world advanced consumer electronics products would be manufactured in PRC but rarely they carry a Chinese brand name or contain advanced technology of Chinese origin.

Standardization has in recent years become a very important element of PRC's technology strategy. There are basically two trends to consider - in the light of the tectonic shift of electronics to East Asia. One is the rising attempts to harmonize interests and development among three countries in East Asia - PRC, Japan and the Republic of Korea. It has become obvious that the countries in East Asia have identified common interests and a more formal approach was established at a ministerial meeting in Seoul in September 2003[10].

The other and more important trend is that PRC wants to establish its **own** technological platform, in as many areas as possible, in order to gain independence from foreign high-tech companies and drastically reduce the level of license fees. Being able to establish or influence global standards has become very vital for national technological efforts.

PRC is becoming the world center for mobile applications – together with the Republic of Korea and Japan – with an installed customer base of around 360 million by the end of 2004. The three largest operators in the world include two from PRC – China Mobile and China Unicom with the former being by far larger than Vodafone that is the number two operator company in the world.

A large number of mobile applications will over the next few years appear on the market and a substantial share of them are likely to be developed by Chinese engineers. The large and expanding Chinese market will drive this development as it requires only limited creativity with major requirements of engineering tasks of a fairly repetitive nature for which PRC would be able to provide ample manpower at low costs.

Semiconductor Industry

Growth of PRC's semiconductor industry continues to be driven rapidly by an increasing domestic demand, and supported by government incentive. However, observers still suggest that throughout 2005 the foundries that have already been established in PRC will primarily rely of orders from overseas customers. The situation is likely to change during 2006 when domestic design companies will begin to deliver product designs for domestic manufacturing.

[8] Zhang Hui, MMTA's vice-president and secretary general
[9] Jang Lintao, MMTA President
[10]

The global semiconductor industry has changed dramatically during the past few years in response to demand and incentives to locate new plants in PRC. In 2000, half of the plants under construction in the world were in Taipei,China, with at the time confirmed plans to build another plants over the next eight years at a cost of $70 billion[11]. A number of plants are either under construction, operational or planned in PRC. One important factor has been the attractiveness of investment in PRC through its 17 percent value-added tax (VAT) on imported semiconductors as opposed to a 3 percent VAT on those made in PRC.

Other factors are PRC's industrial development strategy that has provided concessions in industrial parks and actively sought foreign investment. PRC has sought a followership strategy rather than making large-scale investments in R&D projects that has been the case in Japan and Europe. However, the most important factor in the longer perspective is a rapidly expanding market for semiconductors, requirements of being close to customers to meet changing and more sophisticated needs. This is exemplified by German chip maker Infineon Technologies that is planning an assertive expansion in PRC, which it considers one of the world's most dynamic semiconductor markets[12].

The company in September 2004 opened a memory chip assembling and testing joint venture in Suzhou, in the form of a joint venture China-Singapore Suzhou Industrial Park[13] The venture, will have a maximum capacity of 1 billion chips per year and employ 1,000 people, and eventually requiring a total investment of US$1,000 million. PRC becoming a major car producer is seen as in important factor in Infineon's strategy. Infineon will support PRC's automotive semiconductor by transferring know-how to meet higher emission and safety standards. The underlying factor is that PRC is the world's fastest-growing automotive semiconductor market where Infineon wants to maintain a strong position. The research company iSuppli predicts that the size of PRC's car electronics market will grow from US$1,000 million, in 2002, to US$5,500 million in 2007 – with automotive semiconductor consumption increasing from US$416 million, in 2002, to US$1,4500 million, in 2007. The annual demand for integrated circuits in PRC is expected to reach US$36,000 million by 2006[14].

The start of the modern semiconductor industry in PRC can be traced to the 8th 5-Year Plan[15] which covered the years 1991-95 and a number of multinational companies established initial operations. PRC in 2000 produced a low US$900 million worth of semiconductors compared with $11,000 million for Taipei,China, and most of the productions was rudimentary. The US government in the past restricted access to advanced semiconductor technology and still does for certain technologies and are also influencing other countries to do the same under the Wassenaar agreement, that involves 33 countries. The object was hindering the transfer of technology that could be

[11] How China Is Quickly Capturing The World's Semiconductor Industry, Manufacturing & Technology News, Vol. 10. No. 15 (August 2003)
[12] Li, Weitao, Infineon plotting China expansion China Business Weekly, September 27 2004 (http://www.chinadaily.com.cn/english/doc/2004-09/27/content_378183.htm)
[13] Infineon already has a production facility for logic devices in Wuxi, and a subsidiary in Xi'an that is focused on IC design, and another subsidiary in Shanghai for applications. The new facilities in Suzhou will include an IT Development Centre that will support manufacturing processes.
[14] Ibid.
[15] This included Project 909 with ambitious goals for building IC plants and developing required technical expertise.

used in the military sector. An even more serious hindrance at the time was lack of skilled technicians and managers which partly reflected the turmoil of the Cultural Revolution. However, a report General Accounting Office from two years indicated that several of PRC's factories, using foreign capital and technology, were only one "generation" or less behind the world's leading semiconductor makers[16].

The microelectronics industry in PRC, especially the integrated circuit segment, has always been regarded as strategically important, and was awarded priority when PRC formally announced the four modernizations program in the late 1970s. However, in an interview 2003 at the Ministry of Information Industry an official argued that PRC should rely on foreign direct investment to establish the costly and complex production facilities that are required for IC production[17]. This would be the quickest way to improve the IC industry, while PRC domestically would concentrate its resources on chip design. China Center of Information Industry Development (CCID) argues that now is the right time for the multinational companies to enter PRC's IC market as it will be one of the important bases of global electronic and information products with an expanding domestic market[18]. CCID argues that the development of a robust domestic IC is one of the government's main industrial priorities which is supported by favourable policies and – with an advantage in low cost production and rich human resources.

Until recently, there hardly existed any wholly foreign-owned enterprises in any Chinese industry. However, the Chinese government has made it clear that such investments are now welcome and several 100 percent foreign owned semiconductor producing enterprises now exist or are being established, including the following ones[19].

1. **Motorola** Tianjin Integrated Semiconductor Manufacturing Complex, Operational in 2001 with a total investment in the range of US$1.5 billion
2. Suzhou **Matsushita** Secomiconductor
3. Wuxi Huazhi Semiconductor Co. will be transformed into a wholly-owned Toshiba subsidiary
4. Taiwan Semiconductor Manufacturing Corporation (**TSMC**) Shanghai, Songjiang HiTech Park
5. Ultimate Semiconductor (a Malaysian enterprises that signed an agreement with Shanghai government in 2003)

PRC has also attracted a number of multinational foundries. The report commissioned by the Semiconductor Industry Association (SIA) in the US says that the new semiconductor foundries being established in PRC are unique in the country's context not only because they separate the design function from production, but because the enterprises themselves much more closely resemble Western multinational corporations than any prior Chinese semiconductor enterprises, all of which have been at least partially government owned and controlled. They include the following[20]:

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[16] Iritani, Evelyn, China's Next Challenge: Mastering the Microchip 3002, Times, October 22 2002, (http://justin.deepdrift.com/smic.htm)
[17] Private communication from MII official, November 2003
[18] CCID presentation at Asian Semiconductor Industry Conference 2004, organized by Sangyo Semiconductor News Agency, January 1 2004.
[19] Howell, Thomas R. et al., China's Emerging Semiconductor Industry – The Impact of China's Preferential Value-Added Tax on Current Investment Trends, Prepared by Dewey Ballantine LLP for the Semiconductor Industry Association, Washington. D.C. October 2003
[20] ibid.

1. Semiconductor Manufacturing International Corporation (SMIC), Shanghai, with investment from Shanghai Industrial Holdings, Avant, and others
2. Grace Semiconductor Manufacturing International (GSMC), founded in 2000
3. He Jian Technology Corporation, China-Singapore Suzhou Industrial Park
4. Beijing Semiconductor Manufacturing Corporation (BJSMC), in collaboration with the Beijing Municipal Government, Beijing Economic and Technical Development Area (BDA), and Shougang Iron and Steel. (BJSMC will accommodate facilities for the partnership between SMIC and Infineon Technologies
5. Wuxi CSMC-Huajing, has been operating since 1997

The SIA report also states that a long-standing source of weakness in Chinese semiconductor industry has been the shortage of makers of semiconductor equipment and materials, assembly, testing, packaging and logistics firms. An earlier review stated that[21] "PRC is still incapable of producing most of the equipment used in an 8-inch IC production line, though it can produce some supplementary machinery. As for 6-inch lines, Chinese firms are technically capable of producing almost all required equipment but no one firm is manufacturing enough to be considered a world-class producer."

However, the SIA report argues that this problem is rapidly being addressed in both Shanghai and Suzhou as leading semiconductor enterprises, as well as materials, design and support firms are establishing operations in Zhangjiang HiTech Park, with its Shanghai Zhangjiang Semiconductor Industry Base (ZSIB) and the Suzhou Industrial Park. ZSIB is well on its way to become a major centre for semiconductor production in PRC, while Beijing Economic-Technical Development Area plans to establish a complete industry chain surrounding the new semiconductor foundries being located there.[22] PRC has in the past not been a major market for major equipment suppliers because of the low production volumes inside PRC as well export-control restrictions. However, by 2010 PRC could have become one of the biggest markets for semiconductor-related equipment, partly served by domestic companies. In the meantime PRC will have to import most of needed equipment.

Aircraft Industry

The aircraft industry is one of the sectors where PRC presently perceives a most conspicuous trade imbalance. See appendix. PRC is over the next 15 years expecting a rapid and substantial expansion of air transportation, primarily to meet domestic needs. The country is now in the process to consolidating and combining its various aircraft-related plants into new and viable structures. PRC is following a two-leg strategy with a rejuvenation of existing plants and entering into agreements with foreign partners for which an illustration is provided below.

China Aviation Industry Corporation I (CAICI) and China Aviation Industry Corporation II (CAICII) originated in the late 1990s from the former Aviation Industries of PRC, and are still state-owned holding corporations controlled by the Government. The latter includes 54 industrial enterprises and 3 institutes which are involved in helicopter aircraft, engine and airborne equipment etc. and other 22 enterprises and institutes that are directly controlled by CAICII which also holds 50% of shares of the China National Aero-

[21] Simon, Denis, The Microelectronics Industry Crosses a Critical Threshold, The China Business Review 2001
[22] SIA report

Technology Import & Export Corporation (CATIC), and the China Aviation Industry Supply and Marketing Corporation[23].

CAICII was the first company, to be listed, among the country's 10 most sensitive and largest military business conglomerates under the direct control of the State Commission of Science Technology and Industry for National Defence (SCSTIND), the top governmental body in charge of the country's national defence industry[24]. With a focus in the car industry it is different from CAICI as it has fewer military businesses.

CAICI in 2003 received approval by the State Council, to utilize RMB5,000 million for a pre-study of the ARJ21 regional jet aircraft and launched manufacturing bases in four industrial cities[25]. In parallel CAIC II had enter into a joint venture with Embraer in Brazil, with an equity investment of US$25 million of which 51 per cent is taken by Embraer – with a planned annual production capacity of 24 ERJ regional jets. Mauricio Botelho, president and CEO of Embraer, said the successful maiden flight suggests this advanced regional jet will soon enter the Chinese market[26].

PRC's domestic development of the ARJ21 and its joint venture with Embraer to produce the EMB170 in PRC are clear indications of PRC's long-term ambitions to join the league of the two global makers of large transport and passenger planes – Airbus and Boeing.

The Aviation Industry Development Research Centre of China has estimated that the country's civil aviation fleet would have to add 1,400 large jet liners by the year 2022, which if all are imported, as in the past, would cost in the region of US$100 billion. Ministry of Science and Technology (MOST) will together with other agencies be involved in sizeable science and technology development programme to support the aviation industry over the coming 20 years. A senior aviation industry executive declared in March 2004 that he anticipates PRC's first large aircraft to fly by 2018[27]. Large aircraft refers to aircraft with load capacity exceeding 100 tons and passenger capacity of more than 200 passengers.

Today decision makers within the industry consider that PRC's aviation sector will be incomplete without developing its own civil aircraft industry. They gain support for national defence purposes as well as the size of PRC's market – although facing fact that Boeing and Airbus combined are de facto sole suppliers of large aircraft in PRC. Liu Gaozhu, President of AVIC I realizes that PRC since 1970s, has sought to develop civil aircraft, first by itself, then through means of subcontracting and co-operation, and that the efforts have virtually ended in failure, either because the planes made could not match clients' needs, or PRC did not own independent intellectual property rights. However, he and others today feel that the time is ripe for PRC to initiate a large aircraft programme that would be successful. PRC should first develop large cargo aircraft

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[23] China's Aviation Industry Has Broad Investment Portfolio, January 11 2002 (http://english.people.com.cn/200201/10/eng20020110_88412.shtml)
[24] Flagship Aviation Company Takes up Historic IPO Mission, People's Daily June 25 2002, (english.peopledaily.com.cn/ 200206/25/print20020625_98520.htm)
[25] Zhang Yong, Jet production set to start, China Daily June 7 2003, (http://www.chinadaily.com.cn/en/doc/2003-05/07/content_164336.htm)
[26] China Daily, First China-built regional aircraft takes to skies, December 17 2003 http://www.chinadaily.com.cn/en/doc/2003-12/17/content_290965.htm
[27] China's first large aircraft to fly by 2018, China Daily, March 17 2004

before developing large passenger aircraft and the involvement of private business would be important to speed up the reform of needed research and development.

Boeing and Airbus are increasing their production in PRC thus making the country a major world producer of aircraft parts and components[28]. Their increased interest in sourcing from PRC reflects technological achievement of PRC's aircraft industry. Boeing plans increase production rates of model 737 airplane assemblies built at plants in Xi'an, Shanghai and Shenyang. Furthermore, Boeing is also planning new major airplane maintenance and repair facility in Shanghai, the ARJ21 jet, a new regional jet model to be built by China Aviation Industry Corp I, is supported by Boeing technical contracts. A joint venture BHA Aero Composites Co Ltd will have additional opportunities as airplane production rates and support contracts with Boeing.

Boeing and PRC's industrial co-operation started in the mid-1970s, and there are now more than 3,200 Boeing aircraft in service that include major parts and assemblies built by PRC – corresponding to 25 per cent of Boeing aircraft presently in service. Boeing has procured about US$500 million in aviation hardware from PRC. It might double by 2009 and reach US$1.3 billion by 2010[29].

Airbus and its parent company European Aeronautic Defence and Space Company (EADS), the world's second-largest aerospace and defence company, has also entered into major collaboration PRC's aviation manufacturing industry. Airbus plans to considerably increase its procurement from PRC in the coming years, which would be worth US$60 million annually by 2007 from the current level of about US$10 million annually[30]. Industrial co-operation between Airbus and the Chinese aviation industry began in 1985, when the General Administration of Civil Aviation of Shanghai, now China Eastern Airlines, became the first carrier in PRC to operate the European consortium's aircraft. Contracts for Chinese companies to build sections of Airbus aircraft followed, as did further orders from Chinese airlines.

Aerospatiale, which is now Airbus France, signed the first product sub-contracting agreement in 1985 with Xi'an Aircraft Company on manufacturing and assembling access doors for Airbus A300/A310 wide body aircraft. Since then, the total value of projects subcontracted by Airbus to Chinese manufacturers has exceeded US$500 million. In 2002, Chinese manufacturers delivered more than US$12 million worth of aircraft components to Airbus.

In November 2003, Eurocopter, another subsidiary under EADS, signed an agreement with Harbin Aircraft Industry Group Corp, China National Aero-Technical Import & Export Corp and Singapore-based Technologies Aerospace to jointly produce the five-seat EC120 helicopters in PRC. In October the same year, EADS subscribed for 5 per cent of the issued shares of the Chinese aviation automobile manufacturer AviChina Industry & Technology Co Ltd in the Chinese company's initial public offering on the Hong Kong Stock Exchange. EADS and AviChina will co-operate in the development, manufacturing and upgrade of aviation products, including helicopters and trainers, he said.

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[28] Xu Dashan, Plane parts industry takes off, China Daily, January 15 2004 (http://www.chinadaily.com.cn/en/doc/2004-01/15/content_299000.htm)
[29] Ibid.
[30] Ibid.

Supercomputers in PRC – Usage and Production

PRC is in late 2004 in possession of 14 supercomputers out of a total of 500 which gives PRC a fourth ranking in the world on level of Germany and only behind the US, Japan and Great Britain. The Shanghai Supercomputer Center in June 2004 assembled a machine that at the time became the world's 10th fastest computer, by using more than 2,500 chips designed and manufactured by Advanced Micro Devices in the US[31]. A new geographical trend, which started during the last few years, emerges more clearly. The number of systems in Asian countries other than Japan is rising quite steadily. In this list Japan is listed with 30 systems and all other Asian countries accumulated an additional 57 systems. However, Europe is still ahead of Asia with 127 systems installed. Seventeen of the systems in Asia are installed in PRC - up from 9 systems one year ago. The number of systems installed in the U.S. has also increased to 267 -- up from 247 one year ago[32].

PRC has in terms of continuous thrust in high-performance computing become the most rapidly advancing country in the world. However, PRC's progress in this high-technology field will not become fully recognized until a customer from Thailand or Malaysia would place its order for a supercomputer with a Chinese company. Today PRC has four domestic companies that develop and market supercomputers[33]:

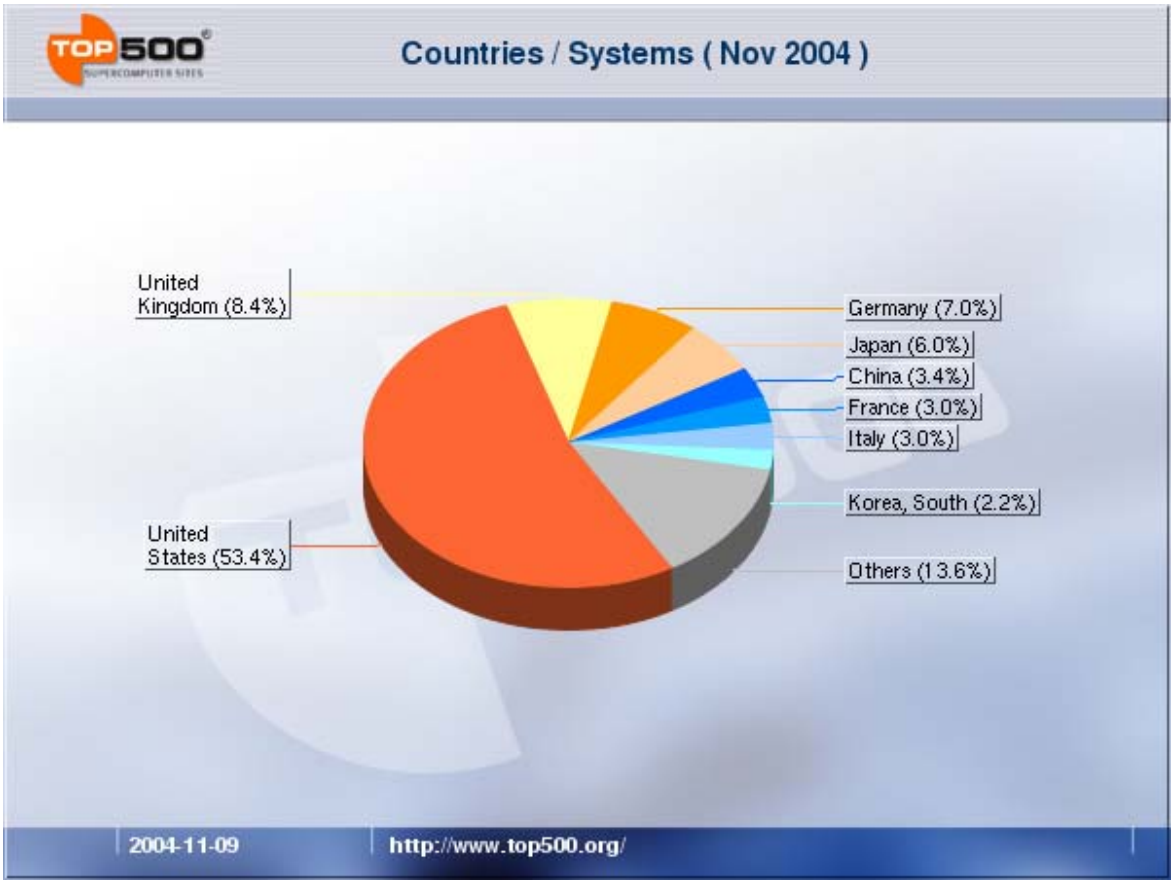
- **Lenovo** (formerly Legend) that was spun-off from the Institute of Computing Technology (ICT) in 1981 and entered the HPC market in 2001. ICT is one of major research institute of the Chinese Academy of Sciences
- **Dawning** that was spun-off from ICT in 1995 and the same year entered the HPC market. The fastest super computer in PRC -- Dawning 4000A, which operates at a speed of 11 trillion calculations per second, was officially started at Shanghai Supercomputer Center in November 2004. It was jointly developed by the Institute of Computer Technology of the Chinese Academy of Sciences, Dawning Corporation and the Shanghai Supercomputer Center.
- **Langchao** entered the HPC market in 2002
- Galactic Computing become the recent entrant in the computer industry in 2004, for which further details are given in the following

High Performance Computing Centers have been established in a number of locations in PRC. Important ones include Department of Computer Science and Technology at Tsinghua University, Institute of Computing Technology, Academy of Mathematics and System Science, Beijing Genomics Institute (BGI), and Shanghai Supercomputer Center.

[31] Markoff, John, Have Supercomputer - Will Travel, New York Times. November 1 2004

[32] 24th Edition of TOP500 List of World's Fastest Supercomputers Released: DOE/IBM BlueGene/L and NASA/SGI's Columbia gain Top Positions, Nov 9, 2004 (http://www.top500.org/news/articles/article_51.php

[33] Stickel, Victor G. Recent HPC Activities in China, ATIP- (First) Chinese HPC Workshop, November 16, 2003, Phoenix, Arizona (PPT presentation)



Galactic Computing in Shenzhen could possibly be such a supplier in PRC's export market for supercomputers. The company that primarily develops blade supercomputers was founded in 1999 by Shell Electric Manufacturing Holdings in Hong Kong, China[34]. A blade supercomputer launched in early 2004 is reported to be the world's fastest computer of its kind, with an average calculation speed of 1 teraflop, with an ability to be scaled up to more than 50 teraflops at peak speed[35].

In the past intelligence experts in the US were deeply concerned that supercomputing capabilities would aid PRC's weapons development. However, it has now become conventional wisdom that PRC's access to extreme computing speeds in itself does not represent a threat the military security of the US. The attention has rather shifted to the threat that PRC would catch up more quickly with the United States in areas that have economic and scientific, rather than military, implications.

Galactic Computing will in the future focus on some ten sectors when developing industrial applications which will be done in collaboration with universities and research institutions in PRC. Chen in October 2004 met with senior Chinese Government officials

[34] Shell Electric Manufacturing Co. is a Group company that has been a manufacturer of consumer electronic goods since 1952. The Group in 2004 employed more than 5,5000 employees worldwide and is involved in three business areas – manufacturing, investments and technology. The last one includes enterprise software and development of blade computers.
[35] China to lead supercomputing sector, October 26, 2004 (http://www.excitecity.com/china/chat/military/messages/39494.html)

from two dozen ministries and bureaus - including education, commerce, public security, information industry, health, science and technology, and the National Development and Reform Commission[36]. Galactic Computing has selected eight partners that will collaborate on areas which include healthcare, chip design foundry, education, entertainment, national security, logistics, new drug discovery and clinical trials, bioscience and exploration for natural resources. These will include Tsinghua University for bioscience; China University of Geosciences for exploration of natural resources; Beijing Jiaotong University for transportation logistics and Nankai University in Tianjin for port logistics. When application systems are ready for marketing Galactic Computing will, with its partners, invite leading Chinese company in each sector to promote relevant applications.

Dr Steve Chen, who used to the a chief architect of Cray supercomputers in the US, now Deputy Chairman and CEO of Galactic computing is very positive about the future and states that "With our technology transfer, I hope we can help PRC in leap-frogging in blade supercomputing technology and applications, and joining the global leaders in information".[37] Galactic Computing expects to receive favourable responses within PRC – from universities, research institutions and companies

Some major computer vendors in the US have taken an interest in blade supercomputers, and the US Government has invested US$90 million in an ongoing project which has been designed to support energy-related research. By October 2004 Shell Electric had invested US$20 million in Galactic Computing, and the company clearly suggests that its development costs will be considerably lower[38]. The company also suggests that the users of blade supercomputers need not discard old computers to buy new ones as they can basically recycle the old ones and add new ones for greater performance or new applications. Many customers may appreciate blade computers as a revolutionary design concept as it significantly boosts the sustainability of computer capabilities.

The situation has changed dramatically since the 1980s when it was difficult to import supercomputers into PRC. Today advanced components become mature and commercially available to build a high-performance computer. The open availability high-speed computer chips have shifted the expertise needing for building supercomputers to the software domain. The challenge lies in developing software that can efficiently link hundreds or thousands of processors together. Despite this change in technology environment the US State Department in October 2004 renewed calls for maintaining the arms sales embargo against PRC, which also extends to restrictions on the fastest computers[39].

Another Chinese company has also made an entry into the supercomputer field. Dawning Information industry has in 2004 delivered one of the most powerful supercomputers to the Chinese Academy of Sciences. However, the processors forming the computer cluster are obtained from Advanced Micro Devices (AMD) in the US, although the cluster will run a Chinese-designed Linux operating system.

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[36] Ibid.
[37] Zhu Boru, US expert drums up support for supercomputing, China Business Weekly, October 26 2004 (http://www.chinadaily.com.cn/english/doc/2004-10/26/content_386388.htm)
[38] China to lead supercomputing sector, October 26, 2004 (http://www.excitecity.com/china/chat/military/messages/39494.html)
[39] Markoff, John, Have Supercomputer, Will Travel, New York Times. November 1 2004

Engineering and Scientific Manpower

Creating and Using Brainpower – The Role of Universities

The university system in particular as well as education in general has received great attention as a fountain well for PRC's future as a knowledge-based economy. Universities have undergone dramatic changes in recent years and it is still too early to fully judge their performance, which must be assessed with regard to undergraduate teaching, graduates studies and research. Universities in PRC have until recently not been involved in advanced research and graduate studies were only introduced after major reforms started in the late 1970s.

The combined effects of a rapid increase of enrolment and a major restructuring of universities will require several years to fully lighten the burden of such changes. The annual enrolment of students in regular institutions of higher education was only 400,000 in1978 and dropped to less than 300,000 the following year which corresponded to about 1.5% of those entering secondary schools in the same year.

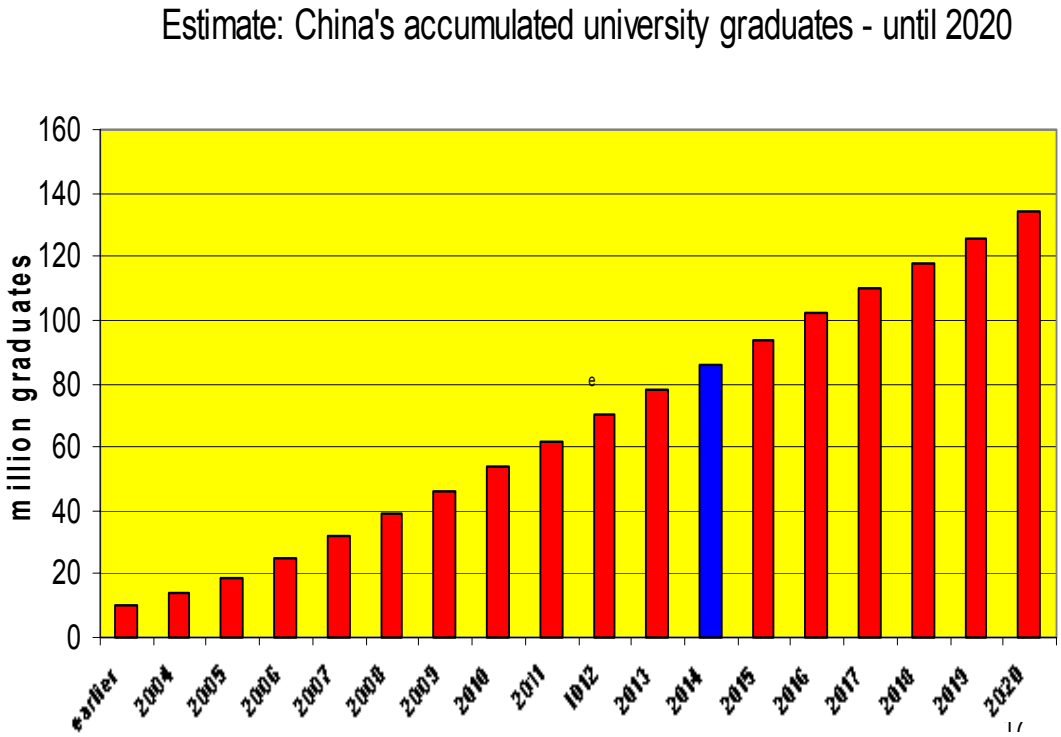
The enrolment in higher education increased rapidly after 1998 with 1,000,000 new students, and the intake expanded to 3.2 million in 2002, which equals ten per cent of the intake in secondary schools the same year. Total enrolment in Chinese universities had by 2002 reached more than 9 million and continues to increase. More than one third of all university students study engineering and including science students the share is close to 40%, and increasing. Thus, Chinese universities will in the predictable future every year graduate at least one million students in science and engineering, the latter with a focus on electronics.

The number of students enrolling as postgraduates has undergone a similar and also very dynamic expansion from a total intake of some 10,000 in 1978 to more than 200,000 in 2002. The number of students having completed postgraduate degrees reached 80,000 in 2002, with a total enrolment of 500,000 in the same year. At the same time 125,000 Chinese were enrolled in postgraduate studies at overseas universities which shows that presently one out of every five Chinese postgraduate students are pursuing their studies abroad.

In 1997 PRC embarked on an ambitious plan reform that should bring a number of its universities into world leading positions during the coming century – the National 211 Project[40]. Selection of one hundred universities is expected to create a necessary focus on higher education to receive special attention and favorable funding. Simultaneously many universities merged into more comprehensive entities and are recently governed only by the Ministry of Education.

Assuming that the expansion of PRC's higher education will continue to expand with national annual intake higher than that of Ningbo PRC could by 2020 have a total of more than 120 million citizens having received education in universities and colleges. Simultaneously it could be expected that 25-30% would have received degrees/diplomas in engineering or science disciplines (see figure). However, there can be little doubt that this expansion would require not only substantial financial resources but also daunting requirements on teaching staff to raise quality standards.

[40] 211 stands for the objective of bring a number of Chinese universities into a Global One position in the 21st century



Perspectives on Biotechnology in PRC

PRC has started to create a durable foundation, based on a number of significant measures that, that could develop into a globally competitive research-based pharmaceutical industry. The pharmaceutical industry in 2002 had a market size of US$6.8 billion and ranked as the seventh largest in the world and is going to be the fifth largest in 2010.[41] Aside from PRC's rapidly expanding gross domestic product (GDP) and increased access of the population, in general, to healthcare products, there are a number of key factors that could propel an industry based on research, to the front rank within the text two decades. They include attention given to the sector in government priorities, the expansion of public research institutions, increasing acceptance of intellectual property rights (IPR) and its integration into research strategies, an already existing industry and the attention given to the development of human resources. Thus,

[41] Statement of Lee Zhong, President of Elene Pharmaceutical Co. in China as an Emerging Regional and Technology Power: Implications for U.S. Economic and Security Interests, Hearing before the U.S.-China Economic and Security Review Commission, February 12-13, 2004, p. 98

International Federation of Pharmaceutical Manufacturers Associations (IFPMA) envisages the appearance on the global scene of novel Chinese-originated medicines.[42]

Biotechnology is a science-based industry and innovations drive the competition within the sector. The industry took roots in the late 1970s and in the 1980s in the US that still dominates the sector with its specific culture and institutions. Researchers within universities have played an important role often in collaboration with venture capitalists. This has prompted the attempts to establish new integrated companies that specialize in biotechnology products or services. However, these companies are faced with scarcity of long-term funding and often lack complementary assets that are needed for marketing, clinical tests ands product development. These factors have enabled the large pharmaceutical companies to gradually incorporate biotechnology into their activities, initially as research tools.

Collaborative agreements have become very common within biotechnology industry in order to capture innovative activities in various fields. The networks provide both coordination of innovative activities as well as a basis for division of labour, and networks have become more numerous and extensive. It has been observed that the large pharmaceutical companies have a comparative advantage in drug development which always requires clinical tests, although drug discovery as such does not offer any economies of scale. This suggests that the advantages enjoyed by large pharmaceutical companies in market power and access to resources enable them to embark on more risky ventures than small biotechnology firms, which seldom can manage rising costs for R&D and marketing.

Molecular biology has created a fundamentally new knowledge structure which has impelled changes in the way that academic researchers, new biotechnology companies and large pharmaceutical companies organize themselves. One important outcome is the formation and successive evolution of R&D networks, as the knowledge base has continued to expand. It is far from clear if this phenomenon is a transitional, or a permanent feature of the biotechnology knowledge landscape in which a distinct pattern of division of labour in R&D will emerge. However, it is evident in the US and to a lesser extent in Europe that new actors have been driving the expansion of networks while established R&D-intensive pharmaceutical companies simultaneously have absorbed new knowledge within such networks. This would indicate that there exist essential competencies within time-honoured corporations, with R&D-intensity in multi-technology domains, to take in new knowledge and techniques generated outside firm boundaries. PRC's biotechnology policies and advances in its fledgling biotechnology industry should the interpreted in light of the broad panorama, which has been outlined in this paper.

PRC has since 1991 emphasized the development of its biotechnology sector which has been included in its 5-Year plans. Technological priorities are not very different from those of other large countries and include functional genome, proteomics, biochip, animal and plant bioreactor, medication and vaccine based on genetic engineering, gene diagnosis and therapy, transgenic technologies for animals and plants, bio-pesticide, bio-fertilizer and biosafety.

[42] Accelerating Innovative Pharmaceutical Research and Development in China: A Case Study, International Federation of Pharmaceutical Manufacturers Associations (IFPMA) and R&D-Based Pharmaceutical Association in China (RDPAC), April 2003, 38 pp.

The aim of biotechnology development in PRC, as in several other high-priority sectors is to catch up or come close to levels of advanced research and production as practiced outside the country. This will not only require raising the overall research competencies but becoming a leading force in a number of important fields, which can be summarized in the following objectives. First, PRC should make breakthroughs in frontier research fields, which are of a strategic character to the further development of the biotechnology sector. Second, PRC needs to develop and support innovation structures that need to driven by the combined forces of entrepreneurial spirit and high-talented research manpower. Third, biotechnology companies have to move to the forefront of international competitiveness, which would involve partnership with foreign companies and international collaboration.

PRC's Technological Impact

PRC's East Asian Integration

Since the late 1990s, or rather since the end of the Cold War, East Asia has experienced a growing economic, albeit not political, integration. This change has been influenced by a growing worldwide integration as exemplified by the EU and the North American Free Trade Area (NAFTA) and the 10-member Association of Southeast Asian Nations (ASEAN). The formation of an increasing economic interdependence in East Asia has led to the emergence of common regional interests. However, critical observers note that there have been no signs that PRC and Japan, being the two major actors in the region, can be involved in deeper integration before they reach appeasement on their relations between 1895 and 1945.

Although the economic amalgamation with Japan, the Republic of Korea and Taipei,China has been remarkable PRC's integration with the rest of the world is equally noteworthy. The integration is not limited only to trade flows but has also become very significant in PRC's outward flow of foreign direct investment. PRC's outbound FDI reached US$2.9 billion in 2003; with an accumulated total of33 billion in the same year[43]. PRC is becoming the world's fifth largest outward foreign direct investor after the US, Germany, Britain and France but displacing Japan. By the end of 2003 some 3,400 of PRC's enterprises had established 7,470 companies in 139 countries[44]. Companies in manufacturing and wholesale and retail business are the largest investors.

PRC's Global Integration

In early November 2004 the president of Brazil took the decision to recognize PRC as a market economy. This move is part of a deepening economic, industrial and technological development between the two countries[45]. In the preceding month of October the countries agreed to jointly work on a third satellite for resource observation, scheduled for placement in orbit in 2006. The satellites will observe and plan for urban expansion and resource conservation, as well as to detect river and ocean pollution and

[43] UNCTAD World Investment Report 2003 (China Daily, October 22 2004
[44] China pours more money overseas, China Daily, October 22, 2004
[45] China's President in Brazil for Space Talks and More, Space Daily November 14 2004 (

deforestation. However, the Federation of Industries criticized the move and argued that it would hurt Brazil's industry, although PRC has become Brazil's third-largest trading partner after the US and Argentina.

Aside from joint interests in space technology the two countries have also found the aircraft industry to be a complementary economic sector, which is exemplified by Empresa Brasileira de Aeronáutica (Embraer). The company has become one of the largest aircraft manufacturers in the world by focusing on specific market segments with high growth potential in regional, military, and corporate aviation.

Outward Flows of FDI

PRC's outward investment in industry has risen most remarkably in mining which accounted for close to 50 per cent of outward industrial FDI in 2003. The following examples from Australia illustrate this development.

The Southland Colliery in Hunter Valley in New South Wales was in 2003 seriously damaged by fire and the owner company collapsed into receivership. In autumn 2004 PRC's largest listed coal company – Yanzhou Coal - decided to buy the idle coal from the creditors at a cost of US$23 million and invest another 70 million (AU$100) for reconstruction. Initial production will be restored by the first half of 2005 and Yanzhou has announced that it will annually produce at least two million tons[46]. Coal demand in PRC is expected to reach 1,700 million tons in 2004 and Chinese companies are more and more moving to secure supplies by buying assets in Australia, similar to the pattern of Japanese investment in the 1960s[47].

Shanghai Baosteel Group Corporation (SBGC) PRC's largest steelmaker, and Hamersley Iron (Rio Tinto) formed a joint venture to mine iron ore in, Western Australia (Paraburdoo) in 2002. Initial capital outlay for the project was $A124 million with Hamersley holding a majority share. Hamersley built the mine and will operate it under the joint venture agreement. The mine is expected to run for 20 years and supply 200 million tonnes of iron ore to SBCG at a values of AU$A7,000 million – with mining starting in April 2004.

Shougang Corporation Chas through its wholly-owned subsidiary China Shougang International Trade and Engineering Corporation took a 5 per cent equity share in a joint venture to expand the Hlsmelt project. The joint venture was formed in April 2002 between majority owner Rio Tinto, Nucor Corporation, Mitsubishi Corporation and Shougang. The project includes construction of plant at Hlsmelt's existing site southern Western Australia (Kwinana), at an investment costs of AU$A400 million. The plant will produce up to 820,000 tonnes of high quality pig iron. Construction of the plant commenced in January 2003 with expected completion by the end of 2004.

The Wheelarra Joint Venture has been set up by BHP Billiton Ltd. to annually sell 12 million tonnes of iron ore per year over 25 years to four Chinese steel mills - Wuhan Iron Steel Group Corp, Maanshan Iron and Steel Co Ltd, Jiangsu Shagang Group Co Ltd and Tangshan Iron and Steel Co Ltd. The four Chinese mills will take a 40 per cent interest in a sub-lease over BHP Billiton's mine in Western Australia (Jimblebar). BHP Billiton will retain a 51 per cent interest in the projects with two other Japanese partners taking

[46] Torunson, Andrew, Chinese resuscitates burnt-out Hunter mine, The Australian, October 12, 2004
[47] Invest Brief No. 2

minor stakes. BHP Billiton expects the relationship between PRC and itself to provide further opportunities for its other businesses, notably metallurgical coal and manganese.

The Chinese government has since early 2003 displayed an increasing willingness to allow foreign capital and expertise to enter its mining industry[48]. The current situation makes the situation exciting for foreign interests as the country is "under-explored and under-mined"[49], and in 2004 only one foreign company was actually producing metal in PRC – Sino Gold from Australia. It is clear that the Chinese Government would hold on to state ownership and would control exploration and mining order. However, "Chinese technocrats also stressed that PRC would remain on an equal footing: what it might sell to foreigners it might also buy from foreigners. Witness PRC's foray into Australia's iron ore and LNG activities over the past two years. 'While we encourage foreign businesses to participate in the development of the mining industry in PRC, we also encourage Chinese mining enterprises to go overseas for co-operation with the international mining industry', said Wang Min, Vice Minister of the Ministry of Land and Resource[50]."

Conclusions – Competition and Collaboration

PRC is still a developing country and is also in transition from a command economy to a market economy; therefore its national innovation system has to be transformed. In the process the responsibility of technological learning has been shifting from the central research and design institutes to enterprises. Thus, industrial experience and technological capacity are nowadays accumulating more and more at the enterprise level.

PRC's is showing considerable prowess in exporting high-technology products, although still with a strong origin in imported technology and components, and primarily based in foreign direct investment. Traditional measures indicate substantial and rapid changes when measuring S&T inputs, although still weakly reflected in technological output. This suggests that PRC should be compared with the situation and experience of Japan in the early 1970s after which it took the country another 20 year to reach the status of a technological superpower. Thus, it might be more relevant to look for technological upgrading in the mushrooming of industrial clusters, particularly in PRC's coastal areas. A number of such clusters are likely to evolve into strong innovative capability, and future centers of excellence.

Being an economy in transition implies that the national innovation of system is being transformed, i.e., the responsibility of carrying out technological learning process will be shifted from the central research and design institutes to enterprises, and enterprises will learn from accepting market economy rules. As industrial experience and technological capacity accumulating more and more at the enterprise level, Chinese companies are still learning to turn out innovations that can best serve the domestic market.

The importance in learning lies not only in acquiring technologies, but more in promoting technological progress by releasing market forces. The gaining and accumulating of market experience – institutional settings, effective incentive mechanisms, developing marketable products, selling new product in the market and so on is more important than

[48] Wyatt, Steve, China's pitch as new mining eldorado, The Australian Financial Review, November 18 2004,
[49] Ibid.
[50] Ibid.

just acquiring a particular technology as such. However, this intensive learning process has primarily been concentrated in PRC's coastal areas – where institutional innovations and expansion of the formal training and higher education may be most significant contributing factors to PRC's continued progress.

Appendix

PRC's Trade – Import and Export for Selected Categories

Imports and Exports by Category of Commodities (Customs Statistics)[51]

(USD 100 million)

Categories of Commodities	2002		2003	
	Exports	Imports	Exports	Imports
Total Value	**3255.96**	**2951.70**	**4382.28**	**4127.60**
Minerals	**98.39**	**244.78**	**127.35**	**377.03**
Chemicals and Related Products	**146.14**	**243.02**	**185.27**	**317.89**
Plastics and Related Products; Rubber	**100.27**	**198.46**	**125.32**	**247.45**
Textile Materials and Products	**578.49**	**169.93**	**733.46**	**192.92**
Base Metals and Related Products	**189.07**	**262.81**	**251.20**	**393.84**
Machinery; Electric Equipment and Accessories; Recorders; Video Recorder and Accessories	**1159.21**	**1253.88**	**1723.34**	**1754.09**
Locomotives; Vehicles; Aircraft; Ship and Related Transportation Equipment	**105.48**	**115.19**	**155.92**	**175.07**
Aircraft; Spacecraft and Parts Thereof	4.39	40.52	4.39	44.61
Instruments; Related Parts and Accessories	**95.23**	**144.21**	**131.05**	**261.73**

[51] China Statistical Yearbook 2004, China Statistics Press, Beijing, September 2004