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From Technological Catch-up to Innovation: The Future of China's GDP Growth



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From Technological Catch-up to Innovation

Summary

Income gaps among countries are largely explained by differences in productivity. By raising the capital/labor ratio and rapidly assimilating technologies across a wide range of activities, China has increased factor productivity manifold since 1980 and joined the ranks of middle income countries. With the launch of the 12th FYP, China has set its sights on becoming a high income country by 2030 through a strategy combining high levels of investment with rapid advances in technology comparable to that of Japan from the 1960s through the 1970s and Korea's from the 1980s through the end of the century. During the next decade, more of the gains in productivity are likely to derive from technology absorption and adaptation supplemented by incremental innovation. By 2030, China expects to have pulled abreast technologically of the most advanced countries and increasingly, its growth will be paced by indigenous innovation which pushes outwards the technology frontier in areas of acquired comparative advantage. Both the first stage and the next will rest on the success of a number of policies focused on: competition and the evolution of the business sector; skill development; R&D; national and international networking to promote innovation; and the nurturing of innovation in major urban centers.

A competitive market environment is the precondition for a steady improvement in productivity. Starting in the late 1980s, for example, market oriented reforms stimulated entry and competition in most manufacturing sub-sectors. Even in some "strategic" or "pillar" industries (for example, airlines and telecommunications) the breaking up and corporatization of incumbent providers in 1990s created new competitive forces. More recently, the phasing out of tax incentives which had favored foreign investors stimulated competition by leveling the playing field with domestically-owned firms. China's WTO accession in 2001 increased competition from imports and the large volume of FDI has led to a further intensification of competitive pressures. Sustaining this trend through institutional reforms and measures to enhance the supply of risk

capital, will be critical to the making of an innovative economy, as it will stimulate the deepening of the private sector, reduce barriers to firm entry and exit, promote the growth of dynamic SMEs, induce the SOEs to raise their game (and pave the way for further reform), and result in national market integration as well as much needed regional or local specialization of industry.

The speed with which advanced technologies diffuse and the capacity to innovate will be keyed to the availability of a vast range of technical and soft skills for example, management, research, design, production, effectively harnessing IT support, and marketing and customer relationships. By 2030, China is expected to have up to 200 million college graduates, more than the entire workforce of the United States. Moreover, the quality of university training is improving rapidly – only five other countries have more universities than China in the top-ranked 500 universities of the world, compared to twelve just eight years ago. Even so, the quality of tertiary education more broadly is a matter of concern and employers are experiencing a serious shortage of skills. For China to become an innovative knowledge economy, both the private sector and the government need to invest more in building analytic and complex reasoning capabilities, enhancing scientific literacy and the knowledge base of students, encouraging creativity and instilling communication and teamwork skills. To increase the volume and quality of skills, China will have to rely more on innovations in pedagogical techniques involving the greater use of multimedia and flexible online training customized to the varying needs of students so as to raise the productivity of the education sector overall and to maximize the benefits from the limited pool of talented instructors and the available physical facilities. Traditional standardized approaches to training by way of lectures to large classes may need to be rethought with institutions being encouraged to experiment and given the autonomy to do so. In this context, the more active participation of leading foreign universities would be advantageous.

Spending on R&D is on a steep upward trend which will enlarge the production of ideas and prepare the ground for innovation. But because most applied research and innovation are done within firms and the majority of scientists will be employed by

businesses the commercializing of ideas will flourish and drive productivity when firms make innovation a central plank of their business strategies. How quickly firms take advantage of the knowledge capital being created by R&D will be a function of market growth and competition, the quality of the workforce and fiscal and other incentives prioritizing research intensive activities.

An adequate volume of much needed basic research, by virtue of its public good characteristics, will depend upon government initiatives and funding. Government agencies and key universities and research institutions will need to take the lead especially in the high risk, blue skies research through well targeted incentives, by committing a sufficient (and sustained) volume of funding to high-caliber institutions, and by means of prizes and awards. In the U.S, the National Institutes of Health have played a central role in boosting innovations in life sciences, as have agencies such as the Department of Energy and DARPA.

Increased publishing of scientific papers and patenting is likely to have only a small impact on productivity growth – even if China is able to raise R&D spending to 2.2% of GDP by 2020 – unless the quality of this research and its commercial relevance and uptake is substantially increased. Good research must be complemented by a stringent and disciplined process of refereeing and evaluation of research projects and findings. The research community needs to take the initiative here and uphold ethics and set high standards, with public agencies providing the ground rules. Universities can also more actively reach out to the business community in order to maximize the relevance of the research conducted, and serve the cause of learning by promoting public lectures, exhibitions, and contributing to the teaching of science in local schools. Beyond that, it is up to firms to transform research findings into profitable products and services.

The central government can help build country wide research networks to mobilize national talent, and create consortia comprised of firms from inland and coastal areas so as to raise the technological levels of all participants through cross fertilization.

Similar consortia have been successfully sponsored by governments in Japan, the U.S. and Taiwan (China) and they can help China develop more “global challengers”.

Many high tech multinational corporations have invested in R&D facilities in China (including in inland cities such as Xian and Chengdu). This should be further encouraged because of its significant long run spillover effects, the reputational gains for Chinese cities which are fast becoming science hubs, and the contribution such research can make to industrial upgrading. Closer collaboration and partnerships with MNCs on the basis of mutual trust and recognition will contribute to the making of a dynamic and open innovation system. In this context, an efficient and discriminating patenting system that reflects the experience of the U.S. and European systems (both of which are in the throes of reform) and effective protection of intellectual property especially in fields such as biotechnology, nanotechnology, software and multimedia, will expedite the growth of China’s indigenous innovation capabilities.

Innovative cities will be the locus of technological advance in China as in other advanced countries – and urban development strategy intersects with strategies for technology development and growth. Innovative cities take the lead in building large pools of human capital (especially in attracting many science and technology workers) and in embedding institutions that support the generation, debate, testing, and perfecting of new ideas. Innovative cities serve as the axes of regional and even international knowledge networks; they derive technological leverage from an industrial base that employs scientific and technological talent; they are home to a few leading, research oriented firms; and they invest in state of the art digital networks and online services. Such cities thrive on the heterogeneity of knowledge workers drawn from all over the country – and the world. Moreover such cities are closely integrated with other global centers of research and technology development. Finally, innovative cities are “sticky” because their leading edge in design, assets, attributes, and governance attracts and retains global talent. International experience suggests that stickiness derives in large part from the presence of world class research universities which China is committed to creating. To succeed in stimulating urban innovation, China will need to endow its

leading institutions with a measure of autonomy from government but also to ensure that they are disciplined by competition and remain efficient providers of services. These universities must interact with employers to mix technical and soft skills as well as impart the latest industry know-how. China's front ranked schools must mobilize the funding and staff faculty positions to sustain cross disciplinary post graduate and post doctoral programs, introduce innovative approaches to imparting knowledge and analytical skills, and establish specialized, well staffed research institutes some of international standing. An important contribution universities can make to innovation is to groom the entrepreneurs of tomorrow who can transform ideas into commercial products and services.

The search for and embrace of green technologies by innovative cities will provide an additional boost to both research and commercialization. Energy pricing reform and the enforcing of national environmental and energy efficiency standards will generate pressures to upgrade technologies and urban development will be the main venue for introducing new construction materials, and technologies for transport, heating and cooling and many others urban needs. Demand-side instruments such as government procurement and standard setting can also spur innovation. The key to success however, will lie in genuine open competition.

From Technological Catch-up to Innovation: The Future of China's GDP Growth¹

China has set its sights on becoming a global innovative powerhouse² by 2020. Policymakers reason that productivity gains from structural changes³ and technological catch-up⁴ will be largely exhausted within a decade and thereafter growth rates in the 6-7 percent range will be increasingly tied to productivity gains stemming from innovativeness in its several forms⁵. The purpose of this chapter is twofold: First is to examine the scope for productivity gains even as the technological gap between China and the advanced countries narrows and suggest how China could hasten the pace of technological catch-up by creating a more competitive economic environment and a world class innovation system. Second, is to sketch a menu of policies that could help to make innovation a major driver of growth. The two are closely interrelated. Policies that promote technological catch-up over the medium run overlap with those that can enlarge innovation capacity over the longer term.

¹ The author gratefully acknowledge the assistance provided by Zhao Luan, Lopamudra Chakraborti and Lihong Wang in collecting and analyzing data and in the production of the report. Thanks are due to Hamid Alavi for his guidance and support throughout the lengthy gestation process, to Douglas Zhihua Zeng for his inputs during the earlier stage of preparation and to Cong Cao, Mark Dutz, Gary Jefferson, Wang Jun, and Jamil Salmi for their most helpful comments and suggestions.

² This is the projection in China's Science and Technology Medium-to-Long Term Plan. An earlier book by Jon Sigurdson (2005) visualizes China as an emerging "Technological Superpower". See also Hu (2011, p.95) who believes that by 2020, China will be an innovative country and the largest knowledge based society in the world.

³ These are the findings of DRC Study on the future growth prospects. The transfer of workers from agriculture to more productive services will continue to yield a productivity bonus for some time. However, once this transfer is largely completed, the increasing share of non tradable services which historically have registered very small or negative increases in productivity, could slow future gains in productivity.

⁴ Comin, Hobijn and Rovito (2006) ascribe the bulk of productivity differentials among countries to lags in the assimilation of technologies.

⁵ In its original form as proposed by Joseph Schumpeter, innovation embraced new products, markets, sources of materials, new production processes, and new organizational forms. To these one can add, design and marketing and the list can go on. Dodgson and Gann (2010, p.11) in their portrait of Josiah Wedgewood the renowned serial innovator maintain that the enduring truth about innovation is that it "involves new combinations of ideas, knowledge, skills and resources. [Wedgewood] was a master at combining the dramatic scientific, technological and artistic advances of his age with rapidly changing consumer demand. The way in which [Wedgewood] merged technological and market opportunities, art and manufacturing, creativity and commerce, is perhaps, his most profound lesson for us".

According to a recent survey by Hall (2011), product innovation was unambiguously more productive than process. In services, marketing, customer relations and the clever use of IT can be decisive.

The chapter is divided into four parts. Part 1 underlines the increasing significance of total factor productivity growth (TFP) as a source of growth⁶, describes China's performance since 1980 and examines sectoral trends. Part 2 reviews China's progress in building technological capacity. Part 3 assesses China's strengths and some of the constraints hindering the development of innovation capabilities. And Part 4 is devoted to the discussion of national and sub-national policies that would enable China to realize its ambition of eventually becoming an innovative nation on par with the U.S.⁷ Japan, Germany and Korea albeit one capable of sustaining a higher rate of growth than these mature economies.

I. Growth Drivers: Betting on TFP

Among the larger East Asian economies only three⁸ were able to transition from middle to high income category during the second half of the 20th century. Japan did so in the 1960s⁹, and Korea, and Taiwan (China) during the 1990s. Japan made the transition by means of a high investment, manufacturing sector-led growth strategy which combined technological catch-up with both incremental as well as disruptive innovations enabled by government industrial and technology policies but introduced by the private sector. The pocket transistor radio, the Walkman, compact automobiles and lean manufacturing were some of the disruptive innovations¹⁰ introduced by Japanese firms

⁶ Jones and Romer (2009) explain the large differences in per capita GDP among countries with reference to both factor inputs and the residual. However, they note that "Differences in income and TFP across countries are large and highly correlated: poor countries are poor not only because they have less physical and human capital per worker than rich countries, but also because they use their inputs much less efficiently."

⁷ Lester (2004, p.5) observes that the real wellsprings of creativity in the U.S. economy are the, "capacity to integrate across organizational, intellectual and cultural boundaries, the capacity to experiment, and the habits of thought that allow us to make sense of radically ambiguous situations and to move forward in the face of uncertainty".

⁸ This count excludes Singapore and Hong Kong (China) which also achieved high income status but because of their size can shed very limited light on policies for China.

⁹ Japan differs from the other two because it was already an industrial power prior to WWII capable of fielding weaponry comparable to that of the Western nations. For comparative purposes however, the Japanese experience remains relevant.

¹⁰ The story of how entrepreneurs and inventors transformed the Japanese electronics industry is well told by Johnstone (1999).

which contributed to productivity gains and export successes¹¹. Korea and Taiwan (China) relied more on technological catch-up also facilitated by high levels of investment in manufacturing although both benefitted from incremental innovation as their industries matured. R&D facilitated technology absorption though its contribution to productivity growth via innovation was quite limited through the late 1990s except in Japan which was in a different league from the other two with respect to its technological capabilities in the 1960s and earlier. While governments actively engaged in deepening human capital, improving access to financing and encouraging the borrowing and assimilation of technology, investment in productive assets, technology absorption and innovation was spearheaded by leading manufacturers assisted by clusters of smaller suppliers¹². Korea and Taiwan (China) graduated from the middle to the high income group of economies largely on the basis of technological catch-up and the building of globally competitive electronics, transport and chemical industries with strong export prospects. Korea and Taiwan (China) began strengthening their innovation systems in the 1980s through public and private investment in research infrastructure, and the acceleration of technological progress¹³ during the 1990s and early 2000s enabled them to cross the threshold and join the high income economies. The importance of innovation has continued to increase and is now paramount for all three economies as their industries are at the cutting edge and growth must lean more heavily on productivity gains deriving in part from successful innovation.

This experience has a number of implications for China's growth strategy. First is the need to fully exploit the potential of technological catching-up in industry and services for at least the next decade. During this period of time, original innovation based on technological breakthroughs may not be as common as innovations combining different existing technologies or introducing innovative designs and special features

¹¹ Japan's technology development and innovativeness is the subject of two excellent volumes: Odagiri and Goto (1997); and Odagiri and Goto (1996).

¹² The keiretsu in Japan, and the chaebol in Korea.

¹³ Among the innovations introduced by Korean companies was the 256 MB DRAM (by Samsung in 1998). The dedicated silicon foundry pioneered by TSMC was a fundamental innovation which transformed the chip manufacturing industry and opened the door to fabless chip designers. See Mathews and Cho (2000); Breznitz (2007); and Hsueh, Hsu and Perkins (2001, specifically the Annex by Ying-yi Tu); and Brown and Linden (2009) on the technological development of Korea and Taiwan (China).

customized for specific markets¹⁴. Second, innovation capability takes years to accumulate and systematically defining and implementing an innovation strategy would begin yielding sizable dividends in the form of frontier expertise and groundbreaking discoveries, most likely in the 2020s and beyond when China would be more in need for a productivity boost from this source. Third the quality and efficiency of the innovation system deserves priority over indicators such as R&D spending, patents and published papers, after all, innovation should create wealth. And fourth, realizing productivity gains will be in the hands of the business sector and it is the dynamism of firms which will be the ultimate arbiter of growth enhancing innovativeness.

A decomposition of China's growth rate is an appropriate starting point. Research conducted by Bosworth and Collins shows that physical capital and TFP¹⁵ contributed 3.2 percent and 3.8 percent respectively to China's GDP growth between 1978 and 2004.¹⁶ During the period 1993 to 2004, their shares were 4.2 percent and 4.0 percent respectively (Table 1)¹⁷ with industry overshadowing other sectors. Capital and TFP contributed 2.2 percent and 4.4 percent of industrial growth during 1978-2004 and 3.2 percent and 6.2 percent from 1993 to 2004 (Table 2). Chen, Jefferson and Zhang (2011) show that TFP rose rapidly in most manufacturing activities during 1981-2008, with electrical and nonelectrical machinery, office equipment and telecommunications subsectors which have benefitted most from technological change, in the forefront.¹⁸ However, comparable gains were achieved by metal and non-metal industries, plastics, rubber, petrochemicals and paper. These findings are reaffirmed by Ito and others (2008). Growth of TFP was strongest for machinery and motor vehicles during 1999-2004

¹⁴ Breznitz and Murphree (2011) argue that China does not need to master breakthroughs to achieve economic success. Instead, China can be a successful second-generation innovator since the spectrum of innovation possibilities is so wide.

¹⁵ TFP is one of the most widely used indicators of growth, but its worth for policymaking purposes is uncertain. Felipe (2008) for instance is outspokenly critical, claiming that "TFP a dubious, misleading and useless concept for policy making".

¹⁶ The sources of growth in China are estimated among others by Wang and Yao (2003); Badunenko, Henderson and Zelenyuk (2008) and Urel and Zebregs (2009), all of whom find that capital played the leading role. Time series analysis arrives at similar results. The many different estimates are surveyed by Chen, Jefferson and Zhang (2011).

¹⁷ See also the estimates on sources of growth and China's share of the world economy in OECD (2010).

¹⁸ Jorgenson, Ho and Stiroh (2007).

(ranging from 2.71 percent p.a. to 2.83 percent p.a.). Large gains were also registered by glass and clay products and paper (See Annex Table 1).

According to more recent estimates by Kuijs (2011), productivity growth slowed to 2.7 percent between 1995 and 2009 and the share of capital rose to 5.5 percent¹⁹. Growth of productivity in services also slowed from 1.9 percent (1978-2004) to just 0.9 percent per annum between 1993 and 2004 (Bosworth and Collins 2007).

Table 1: Sources of Growth (1978-2004)

Annual percentage rate of change

Period	Output	Employment	Output per Worker	Contribution of:			
				Physical Capital	Land	Education	Factor Productivity
Total							
1978-04	9.3	2.0	7.3	3.2	0.0	0.2	3.8
1993-04	9.7	1.2	8.5	4.2	0.0	0.2	4.0

Source: Bosworth and Collins (2007)

Table 2: Sources of Growth by Industrial and Services Sectors (1978-2004)

Annual percentage rate of change

Period	Output	Employment	Output per Worker	Contribution of:		
				Physical Capital	Education	Factor Productivity
Industry						
1978-04	10.0	3.1	7.0	2.2	0.2	4.4
1993-04	11.0	1.2	9.8	3.2	0.2	6.2
Services						
1978-04	10.7	5.8	4.9	2.7	0.2	1.9
1993-04	9.8	4.7	5.1	3.9	0.2	0.9

¹⁹ Chen, Jefferson and Zhang (2011) ascribe the slowdown in TFP growth since 2001 to industrial policies that have reduced allocative efficiency, factor market distortions which divert financial resources to less productive uses and to the diminishing productivity bonus from structural change.

Source: Bosworth and Collins (2007)

With capital spending subject to decreasing returns as is evident from the upward trend in ICORs,²⁰ the scope for raising growth through larger injections of capital is being rapidly exhausted. Moreover, rebalancing of consumption spending will lead to a decline in the share of investment. At the same time, the structural transformation of the Chinese economy is entering a stage when productivity gains from the inter-sectoral transfer of resources will continue tapering²¹. In most OECD countries, TFP growth averaged less than 2.0 percent p.a. between 1995 and 2009²², the exceptions being Korea and Ireland each of which notched up rates of 2.7 percent and 3.1 percent respectively – although Ireland fell to 1.3 percent and Korea to 2.6 percent during 2005-2009²³.

International experience offers the following three pointers: First are the advantages of a continuing emphasis on those manufacturing industries that are likely to deliver the highest returns from catching-up so long as Chinese firms are quick to pursue technological possibilities and strive to maximize efficiency gains. These include industries such as electrical machinery, office and computing equipment, pharmaceuticals, aircraft, motor vehicles, and non electrical machinery, which have demonstrated rapid improvements in technology because they are also the most R&D intensive (see van Pottelsberghe 2008).

Second, catching-up and innovation in services²⁴, promoted by ICT, is likely to play a more prominent role over the longer run as the share of services in GDP will shortly begin to overshadow industry. This would involve incentivizing innovation by

²⁰ Yu (2009). Perkins (2011) estimates that China's capital to output ratio has risen from 3.79 in the 1990s to 4.25 in 2000 – 2007 and to 4.89 in 2008 – 2009.

²¹ Chen, Jefferson and Zhang (2011).

²² Even at its peak, TFP growth was generally less than 3 percent for almost all countries. For example even during its years of rapid growth, Finland averaged 2.8 percent per annum..

²³ The estimates differ. Those above are from the OECD. See Groupe BPCE (2010); Fukao and others (2008); and OECD Statistics Portal <http://stats.oecd.org/Index.aspx?DatasetCode=MFP>

²⁴ Eichengreen (2010) observes that the growth of productivity in China's services sector barely exceeds 1 percent per annum as against 8 percent in industry and the sector accounts for little of the R&D. He calls for a revolution in services in order to catch –up with the U.S.

firms engaged in banking, insurance, retailing, real estate, logistics, and data services and also healthcare and education, two important and growing activities.

Third, lowering market barriers to the entry, growth and exit of firms, will contribute to economy wide improvements in productivity growth by intensifying competition and with it the process of creative destruction (McKinsey 2011).²⁵

The trends in manufacturing are promising. Chinese manufacturers of transport and telecommunications equipment, consumer electronics and textiles and garments are aggressively engaging in backward and forward integration moving from the assembly and testing of standardized products to the design and manufacture of differentiated parts and components and new products that generate higher profit margins.²⁶ These efforts if they are abetted by a consolidation of global production networks (partly because of the pull of agglomeration economies and partly also because of emerging supply chain vulnerabilities²⁷ and transaction costs), could increase the share of higher tech items produced domestically and steadily reduce the imported content of China's manufactured exports, which has already declined from 52.4 percent in 1997 to 50.6 percent in 2006 (Koopman, Wang and Wei 2009). This is likely to reverse past tendencies for imported inputs to increase initially as the skill intensity of production rose (see Moran 2011b).

Product space analysis pioneered by Hidalgo, Hausmann, Klinger and Rodrik suggests that the average sophistication of China's exports is Comparable to that of Malaysia, Thailand and the Philippines (Table 3).

Table 3: EXPY by country

Exporter	1980	1985	1990	1995	2000	2006
Bangladesh	1,483	2,772	3,347	4,097	3,773	5,927
China		5,009	8,231	8,152	9,296	11,743
Indonesia	4,897	4,721	6,481	6,242	8,543	8,291
India	5,783	6,337	7,028	6,335	6,694	9,329
Japan	14,019	14,689	14,449	12,842	13,484	14,532

²⁵ See Comin (2004).

²⁶ As noted earlier, China exports of manufactures overlap with those of the U.S., but wide differences in quality and technological sophistication remain.

²⁷ The Fukushima disaster has further sensitized companies to supply chain vulnerabilities.

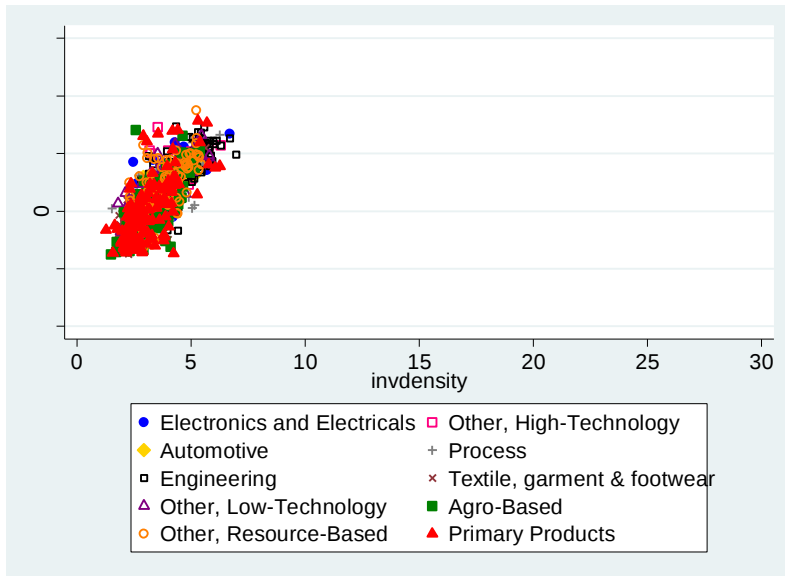
Korea	9,803	10,180	10,258	10,557	11,681	13,719
Malaysia	4,433	5,137	7,912	9,577	10,875	11,897
Pakistan		4,181	4,084	3,944	4,480	5,323
Philippines	5,242	5,093	6,317	7,457	11,297	11,813
Singapore	8,311	9,113	11,248	12,449	12,912	15,079
Thailand	4,954	5,673	7,660	8,559	9,666	11,099
Taiwan						
(China)			10,874	11,107	12,364	14,481
Vietnam					5,806	7,190
Sri Lanka	2,888	3,423	4,261	4,561*	4,749*	5,148*

Note: * denotes that data is for the years 1994, 1999 and 2005

Since 1985, China has broadened its production base and through massive investment, enlarged production capacity and accelerated learning by doing²⁸. As a consequence there is now a wide assortment of products that can be technologically upgraded and from which Chinese manufacturers can diversify into other related products (Figures 1 and 2). In product space terminology, more of the products lie in the densely networked core which multiplies options for industrial diversification and the scope for innovation.

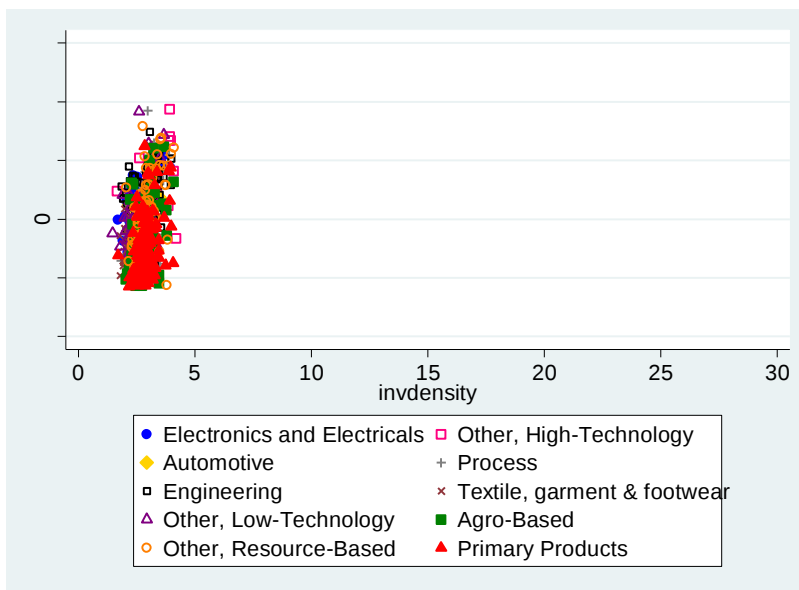
Figure 1: Product Space (1987)

²⁸ An aspect of learning highlighted by Levitt, List and Syverson (2011) and critical to the profitability of electronic component manufacturing for example but also of autos, is a reduction in the number of defects, a function of worker skills and familiarity with the production process and the plant's physical and organizational capital.



Source: Authors' calculations based on UN Comtrade data

Figure 2: Product Space (2006)



Source: Authors' calculations based on UN Comtrade data

A closer inspection of the products in China's export basket with the highest densities that are upgrades, underscores the fact of China's rapid industrial progress. In 1987, the top 10 commodities with the highest densities, implying that they were more sophisticated than the average, were mainly low-tech items offering minimal

opportunities for diversification (see Table 4). By 2006, the composition of the high density products had altered radically with many opening avenues for upgrading into more technologically advanced products with better market prospects (see Table 5). Thus China's industrial capabilities are strengthening as is its competitiveness relative to higher income countries. These findings are similar to those of Felipe et al (2010)²⁹.

Table 4: Top 10 “upscale” commodities with highest density (1987)

Short description	Density	Technology class	PRODY-EXPY
Pyrotechnic articles	0.655046	MT2	451
Manufactured goods, nes	0.558615	LT2	1,325
Children's toys, indoor games, etc	0.474168	LT2	3,163
Travelling rugs, blankets (non electric), not knitted or crocheted	0.461357	LT1	1,934
Umbrellas, canes and similar articles and parts thereof	0.458874	LT2	891
Base metal domestic articles, nes, and parts thereof, nes	0.455813	LT2	981
Other materials of animal origin, nes	0.451113	PP	447
Fabrics, woven, of sheep's or lambs' wool or of fine hair, nes	0.449691	LT1	4,309
Soya beans	0.439272	PP	534
Hydrocarbons derivatives, non-halogenated	0.436489	RB2	4,983

Source: Authors' calculations based on UN Comtrade data

Table 5: Top 10 “upscale” commodities with highest density (2006)

Short description	Density	Technology Class	PRODY-EXPY
Optical instruments and apparatus	0.607906	HT2	4,818
Portable radio receivers	0.542989	MT3	5,612
Children's toys, indoor games, etc	0.528838	LT2	4,149
Other radio receivers	0.525168	MT3	3,470
Printed circuits, and parts thereof, nes	0.523646	MT3	3,574

²⁹ According to Felipe et al (2010) as early as the 1960s, China was exporting 105 commodities (with comparative advantage) from the 779 commodities in their sample, many more than either Korea or Brazil. By 2006, the number had risen to 269, well ahead of Japan (192). Of these, 100 products were from the core of the product space. China continues to export with comparative advantage 69 labor intensive products; its exports of machinery have risen from one in 1962 to 57; it has lost comparative advantage in less sophisticated metal products and gained it in products with higher PRODY. China has also forged ahead with telecommunication and electronic products and office equipment. As a consequence, the unweighted PRODY of China's core exports rose from \$14741 in 1962 to \$16307 in 1980 to \$17135 in 2006 (Felipe et al 2010, p.12)

Knitted, not elastic nor rubberized, of fibers other than synthetic	0.510308	LT1	1,775
Pins, needles, etc, of iron, steel; metal fittings for clothing	0.509124	LT2	219
Peripheral units, including control and adapting units	0.506912	HT1	506
Fabrics, woven, of continuous synthetic textile materials	0.497133	MT2	2,840
Pearls, not mounted, set or strung	0.49101	RB2	5,397

Source: Authors' calculations based on UN Comtrade data

The trend in patenting during 2005-2009, indicates that the changing composition of manufacturing is serving to upgrade domestic technology. Residents of China who registered with the United States Patent and Trademark Office (USPTO) received the largest number of patents for electronic and electrical devices, followed by communications devices, software, pharmaceutical compounds and optical devices (Annex Table 2). Similarly, the overwhelming majority of patents granted to residents of China by the World Intellectual Property Organization (WIPO) were also for electronic, electrical and telecommunication devices followed by chemical³⁰ and biological products³¹ and products grouped under the mechanical engineering category. The sectoral composition of patents held by Chinese residents favors electronics and electrical engineering and differs in this respect from the international distribution of categories as registered with the USPTO and the WIPO (Annex Table 3).

Among manufactured products, electronic, communication and optical devices are likely to remain the technologically most dynamic products, the focus of innovation and a continuing source of increases in productivity in the world and in China. Chinese companies such as Huawei and ZTE are emerging as world leaders in the telecommunications sector and role models for others seeking to establish a significant presence in the global market.

³⁰ Data collected by Thomson Reuters shows that China's patent rankings by subsector are highest for chemical engineering – 2nd after the US. The rankings are 4th or lower for other major subsectors (Zhou and Stembridge 2011).

³¹ The data generated by the Nature Publishing Group indicates that Chinese researchers are increasing their contribution to genetics, clinical medicine and structural biology (Nature Publishing Index 2010).

Entry of firms by Subsector

China's emerging comparative advantage in high technology sectors is supported by data on the entry of new firms. The subsectors with high rates of new entry are metal manufacturing, machinery, electrical, computing and telecommunications equipment. In addition, business, scientific and technical services are growing robustly as China urbanizes and consumption shifts more towards services. The statistics on firm entry for Guangdong (Annex Table 4) reaffirm the importance of garments and leather products as well as the strength of industries producing metal products, machinery and computing equipment. Business services are also a growth sector in Guangdong. Machinery and transport equipment and plastics are the favored subsectors in Zhejiang (Annex Table 4). And in both Zhejiang and in Beijing (Annex Table 4), the conspicuous growth drivers are business and scientific services as is the case in coastal provinces and across the nation. Urban development and the continuing structural transformation of the economy is facilitating the entry of small firms which in turn contributes to patenting and the introduction of new products (See Annex Table 5). Small firms on the average being more efficient in using R&D resources – financial and human – to generate patents (see Annex Tables 5, 6, and 7). Looking ahead, there is more room for growth of services activities and for competition which would raise efficiency.

The data on new domestic firms entering manufacturing subsectors is consistent with FDI data which shows that the two subsectors most favored by foreign investors are computers and other electronic equipment, followed by chemicals, universal machinery and special purpose machinery. The share of computers and electrical equipment while still high has declined since 2004, the shares of the others have remained largely stable (see Annex Table 8).

International experience suggests that the contribution of small and medium sized companies to innovation is likely to be increasing. And this desirable development can be facilitated by measures to reduce entry barriers, including transaction costs for SMEs and making it easier for them to access financing.

II. Building Technological Capacity

Prior to the industrial revolution in Europe, China led the world in technology³². After losing ground for over two hundred and fifty years, China is determined to become a global force in technology, and possibly even the leader, by 2030. China began piecing together a strategy starting in the 1980s with an emphasis on manufacturing capabilities and cost innovation in major product categories. This was followed by increasing acquisition of foreign intellectual property (IP) complemented by reverse engineering. Since the late 1990s, China has attempted to maximize technology transfer through foreign direct investment (FDI) in particular by encouraging multinational corporations (MNCs) to conduct more of their R&D in China³³. The transfers and spillovers induced have fallen short of expectations with research analyzing Chinese and international experience suggesting – albeit with qualifications and exceptions – that MNCs might be a limited source of technological spillovers and those too mostly in the vertical plane and in high tech sectors³⁴. In low tech ones, the spillover effects could be negative. Moreover, where MNCs fear that their IP might be compromised, they are reluctant to introduce the latest technologies or to conduct frontier research aside from taking other precautions to minimize technology leakage³⁵. In the light of this experience, China is redoubling its own efforts at technological upgrading, indigenous innovation³⁶, takeover of foreign firms and their brands by China's leading challengers, and determined efforts by Chinese firms to innovate, build their own brand image and join the ranks of firms that dominate the global marketplace.³⁷

³² This leadership has been convincingly documented by the series of volumes on China's Science and Technology launched by Joseph Needham.

³³ See Walsh (2003).

³⁴ See Moran (2011a&b)

³⁵ See Moran 2011; Fu and Gong 2011; Tang and Hussler 2011; Bai, Lu and Tao 2010; and Fu, Pietrobelli, and Soete 2011.

³⁶ See Gao, Zhang and Liu (2007) on the efforts of Dawning and HiSense to cap manufacturing capability with own innovation.

³⁷ The Forbes Global 2000 generate \$30 trillion in revenue annual, equal to one half the global GDP. China still has only limited representation in this group – with less than 5 percent share of the revenue. The Chinese firms making headway in the sphere of manufacturing are Haier, Lenovo, BYD, Huawei and ZTE.

Planning Technology Development in China

Technology development and innovation is a fairly recent focus of China's development strategy³⁸, hence there are very few Chinese firms that can be counted among the technological leaders in their respective subsectors and are significant producers of intellectual property. Although the research infrastructure and numbers of researchers has expanded manifold, quality, experience, and the institutions that undergird innovation, remain weak. Leapfrogging into the front ranks of innovative nations will depend upon the efficiency of China's technology policies and the response these policies elicit from the business sector³⁹, academia and the providers of supporting services. It will also crucially depend upon the creating of an innovation system that is alive to the global and open nature of innovative activities and their locus in a number of cosmopolitan urban hotspots.

The recently completed 11th Five-year plan stated that China would build competitive advantage based on science, technology, and innovation, and this is a prominent objective of the 12th Plan. In early 2006, the government announced its National Program Outline for Medium and Long Term Development of Science and Technology (2006-2020). Its key pillars include "indigenous innovation", "a leap-forward

Lenovo's experience with the acquisition of IBM's PC business and that of TCL with the takeover of Thomson's TV arm suggests that the acquisition of large foreign firms with brand names can bolster the fortunes of ambitious Chinese companies if they can muster the managerial expertise to harness and grow the reputational capital of the acquired foreign assets and cope with the challenges posed by transnational operations (On Lenovo's circumstances see "Short of Soft Skills" 2009). The acquisition of Volvo the Swedish carmaker by Geely, the privately owned, Hangzhou based Chinese manufacturer, will be another important test case of whether Chinese firms can turn around an ailing foreign company and effectively sustain and capitalize on its reputation.

³⁸ The Chinese government formally adapted the "Strategy for Raising the Nation by relying on Science, Technology, and Education (Kejiao Xin Guo Zhanlue)" in 1995, and established the State Leading Group on Science, Technology and Education in 1998, headed by the then premier Zhu Rongji.

³⁹ See fnnt 35 on the initiatives by Chinese firms and Annex C. Huawei and ZTE are also among the leading indigenous innovators.

in key areas,” “sustainable development”⁴⁰, and “setting the stage for the future.” The strategy calls for increasing R&D in priority areas including ICT, biotechnology, nano-sciences and nanotechnologies, materials, energy, and others⁴¹; it seeks to encourage enterprise-led innovation; to strengthen intellectual property protection; create a favorable environment for S&T innovation; attract S&T talents; and improve the management and coordination of S&T. During the 11th Plan period, the central government’s outlay on science and technology rose by 22 percent per year. By 2010, R&D accounted for 1.75 percent of GDP and it is projected to reach 1.85 percent by end 2011.

Innovation and technology development are assigned a central role in the 12th FYP (2011-2015), with the highest priority given to:

- Strategic industries (energy-saving and environmental protection, next generation information technology, bio-technology, high-end manufacturing, new energy, new materials and clean-energy vehicles). A number of mega-projects with a focus on basic research are earmarked for a large injection of resources starting in 2011. Two that have been singled out are in the life sciences – on drug discovery and on major infectious diseases – reflecting the view that research on biopharmaceuticals and stem cells might lead to profitable innovations;
- Promoting enterprise-led innovation;
- Strengthening supporting services;
- Raising expenditure on research and development to 2.2% percent of GDP⁴²;
- Increasing rates of patenting to 3.3 per 10,000 people.

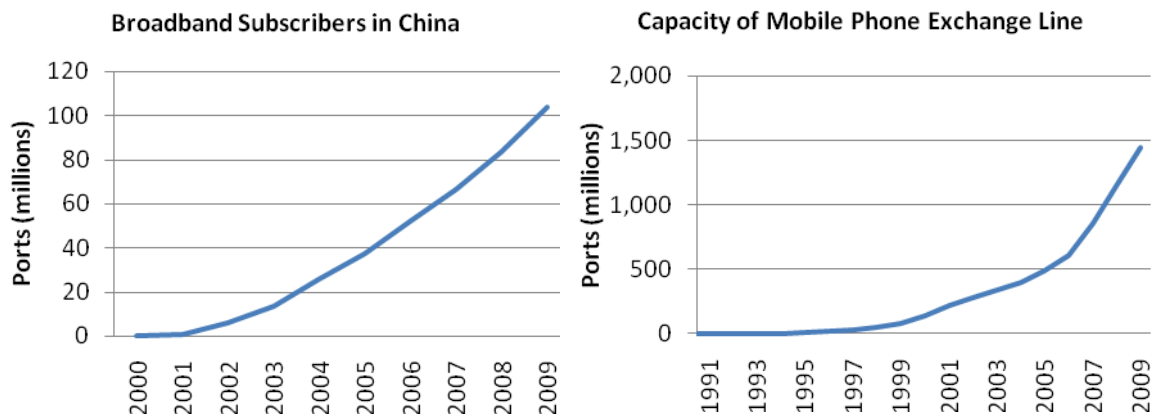
⁴⁰ See Price and others (2011) on the success of China’s efforts to reduce the energy intensity of the economy by 20 percent during the course of the 11th Plan.

⁴¹ Other areas of emphasis are: energy-saving and environmental protection, next generation information technology, bio-technology, high-end manufacturing, new energy, new materials and clean-energy vehicles.

⁴² Gian and Jefferson (2006) note that countries appear to experience a “S&T take-off” when their spending on R&D doubles as a share of GDP and begins to approach 2%. China has doubled its spending since the mid 1990s and on current trends will exceed 2% by 2014. “China Bets Big” (2011). According to one estimate of the returns to R&D, a 10 percent increase in spending per capita raises TFP by 1.6 percent over the longer term (Bravo-Ortega and Marin 2011).

An increase in R&D is being complemented by investments in the physical infrastructure supporting technological upgrading⁴³. Strengthening and more fully exploiting the potential of multimodal transport is helping to raise the efficiency of logistics. And massive investments in renewable sources of power, in a smart grid and rail transport, are expected to reduce energy consumption⁴⁴. Mobile networks have vastly increased their reach adding 517 million users and in 2009 the broadband network gave access to over a 136 million users, compared to 113 million in the United States⁴⁵ (Figure 3).

Figure 3: China Transport Infrastructure and Mobile Networks



Source: China - Broadband Market - Overview and Statistics, June 2010,

<http://www.docin.com/p-72386902.html>; CEIC database

Furthermore, full-time equivalent R&D personnel tripled, from 0.75 million to 2.3 million person-years; and the total number of personnel engaged in Science and Technology (S&T) activities reached 4.97 million in 2008. Some 6 percent of China's

⁴³ China has some of the best equipped laboratories in the world with state of the art measuring and testing devices. Computing power has also risen in leaps and bounds. As of November 2010, China was second only to the U.S. with 41 of the 500 fastest supercomputers in the world (IEEE April 2011). For a period of less than a year (2010-2011), China's Tianhe -1A was the world's fastest supercomputer, before being overtaken by the Fujitsu K computer. This might soon be eclipsed by IBM's Mira computer.

⁴⁴ Installed electricity generating capacity rose from 350 GW in 2000 to over 900 GW in 2010 "China's power generation capacity leaps above 900 million kilowatts, 2010". Temporary shortages of coal and rising prices constrained supply from coal fired plants while inadequate rainfall reduced the supply of power from hydro sources in 2011.

⁴⁵ National Bureau of Statistics.

1700 institutions of higher education are elite Project 211 entities⁴⁶ responsible for training four fifths of doctoral candidates, hosting 96 percent of key labs, and contributing 70 percent of the funding for university research. A total of 218 national priority labs now cover all the major scientific fields⁴⁷.

Between 1996 and 2000, China's global SCI ranking measured by publications increased from 14th to 2nd place⁴⁸. The output of publications soared from 20,000 in 1998 to 112,000 in 2008 equal to 8.5 percent of global output of scientific publications. A study conducted by Britain's Royal Society found that between 2004 and 2008, China produced over one tenth of the published scientific articles as against a fifth by the U.S. putting China in 2nd place ahead of the U.K. which now accounts for 6.5 percent of publications as against 7.1 a decade ago⁴⁹. Chinese research publications lead the field in materials science, physics, chemistry and mathematics. Moreover, Chinese research in nanoscience, which is likely to affect the development of advanced materials for example, is yielding promising results.⁵⁰

However, as yet, China has relatively few high impact articles in any field (Simon and Cao 2009, Royal Society 2011) although according to the SSCI, China's citation ranking rose from 19th place in 1992-2001 to 13th in 1996-2005 to 10th place in 1998-2008 (Hu 2011, p.102).

Mirroring the trend in publications, the number of patents granted to Chinese enterprises dramatically increased from 5,386 in 1995 to 76,379 in 2006⁵¹. The number of

⁴⁶ China is attempting to groom up to 100 universities (including the 75 under the MOE) into top flight world class universities - through the 211 and the 985 program (buttressed by the 863 and 973 programs). Currently about 40 are being targeted by the 985 program.

⁴⁷ Worldwide spending on R&D amounted to \$1.1 trillion in 2007 with spending by Asian countries surpassing that of the EU and approaching that of the U.S (National Science Board 2010).

⁴⁸ See Adams, King and Ma (2009)

⁴⁹ "China shoots up rankings as science power, study finds 2011".

⁵⁰ See Hassan (2005); Bai (2005); Preschitschek and Bresser (2010); Italian Trade Commission (2009); and Leydesdorff (2008).

⁵¹ Patenting is an unreliable indicator of innovation and as patent offices have experienced an increase in applications, their ability to filter the good from the innocuous has declined – especially the filtering of business model, process and software patents applications. Many if not most patents never lead to any commercial outcomes.

patent applications to the WIPO increased from a little under 23,000 in 1996 to 290,000 in 2008 (Hu 2011, p.103). A continuing sharp increase through 2009 propelled China to 5th place in WIPO's rankings, but again quantity has not yet been matched by the quality of the patents.⁵² Incentives to patent have produced a flood of minor design and utility patents contributing little to advances in knowledge or commercial innovation. Most of the high and mid value patents are being registered by MNCs (See Boeing and Sandner 2011 and Table 9)⁵³. Triadic patent filings (with the patent offices of the US, the EU and Japan), a better measure of the worth of a patent, while increasing are few in number and as recently as 2008, Chinese residents had filed just 473⁵⁴.

By official count the number of S&T based private firms increased from just 7000 in 1986 to 150,000 in 2006⁵⁵ and as of 2007, the assets of privately owned Chinese companies were approaching those of the SOEs not including the 100 largest (OECD 2010). Now a small number of Chinese firms, such as Huawei and ZTE in the ICT industry, Suntech Power in solar technologies and Dalian Machine Tool Group in engineering, have reached or are approaching the international technological frontier and demonstrating a growing ability to create technology.⁵⁶ Chinese companies are also mastering the latest technologies in areas such as auto assembly and components, PVCs, biopharmaceuticals⁵⁷, stem cell therapeutics⁵⁸, and high density power batteries⁵⁹, high

⁵² See "China's patents push 2010". However, foreign patent applications comprise two thirds of all effective invention patents (Hu 2011).

⁵³ http://transatlantic.sais-jhu.edu/bin/k/u/cornerstone_project_lundvall.pdf;
<http://www2.druid.dk/conferences/viewpaper.php?id=502529&cf=47>

⁵⁴ The fewness of Triadic filings reflects also the high costs. Some firms take the PCT route (Patent Cooperation Treaty) which establishes a filing date and needs to be followed up with national filings, but permits some delay. See http://en.wikipedia.org/wiki/Patent_Cooperation_Treaty

⁵⁵ See Ministry of Science and Technology (2008)

⁵⁶ Some of this technology is own generated, some is acquired through the takeover of foreign firms. For example, Dalian Machine tools purchased two businesses from Ingersoll International and bought a majority share in F. Zimmermann. Suntech Power acquired the Japanese MSK Corp and KSL-Kuttler Automation Systems in Germany (BCG 2009). See also Zhang, Mako and Seward (2008)

⁵⁷ Gwynne (2010) notes that Chinese Contract Research Organizations (such as Shanghai Genomics/GNI) are now offering services ranging from the development and production of biological drugs using recombinant DNA technology, and research on edible vaccines is on the rise. But overall, Chinese companies hold only a limited portfolio of pharmaceutical patents and lag in this field.

⁵⁸ Gwynne (2010).

⁵⁹ See Adams, King and Ma (2009) on China's R&D effort. Sinovel, Goldwind and Dongfang Electric were the top Chinese producers of wind turbines in 2009, ranked 3rd, 5th and 7th in the world respectively "List of wind turbine manufacturers 2011". China's BYD (Build Your Dreams) is a leader in high density

speed trains, telecommunication equipment, wind turbines⁶⁰, booster rockets, space satellites⁶¹, supercomputers, shipping containers, internet services, electric power turbines, and many other products⁶².

These achievements notwithstanding, the reality is that much of China's export oriented manufacturing industry is still engaged in processing and assembly operations, export competitiveness is predominantly based on low factor costs, and over one half of exports are produced by foreign owned firms or joint ventures. Foreign firms also account for over 85% percent of high tech exports since 1996 (Moran 2011b)⁶³. Having no big marquee brands or core technologies, China reaps only a small portion of rents from high tech exports which accrue mainly to foreign designers and engineers.⁶⁴

How does China's performance to date compare with that of the leading East Asian economies? In terms of growth, China has done better. Growth has been higher over a longer period buoyed by above average productivity gains. But the data on industrial value added and technological indicators suggest that there are plenty of rungs left to climb up the technology ladder. By pouring resources into S&T development, China has begun building research capacity and the experience it will need to become an innovative economy. Although the efficiency of the emerging innovation system is questionable, the quality will need improving and the urban dimension has been relatively

batteries. These and other firms (such as the Galanz Group, the HiSense Group and SAIC) are among the New Challengers in BCG's list of 100 top firms in 2009.

⁶⁰ Goldwind has co-developed a direct drive wind turbine which dispenses with the cost and inefficiencies of a gearbox. See Zhao (2011) on the development of PVCs in China, starting in the mid 1980s with two silicon cell assembly lines.

⁶¹ By 2011, China had launched over a 100 satellites for purposes of surveillance, remote sensing, weather forecasting and telecommunications. (See "Chinese Academy takes space under its wing" 2011). A space station is now in the works. See "China unveils its space station" 2011.

⁶² This list now includes stealthy jet fighter planes. See "Chengdu J-20 2011"; http://www.aviationweek.com/aw/generic/story.jsp?id=news/awst/2011/01/03/AW_01_03_2011_p18-279564.xml&channel=defense

⁶³ See also <http://www.sts.org.cn/sjkl/gjscy/data2010/2010-2.htm>

⁶⁴ For example, while Apple's i-phone, is assembled in China, domestic producers earn an estimated \$25 of the retail price of a high end phone, and for a pair of Nike sneakers, China collects four cents on a dollar. Similarly, for a Logitech wireless mouse, China's share is only \$3 out of a retail sale price of \$40 (Promfret 2010). In general, the rents from manufactured products tend to be short lived because entry barriers are lower and competitors are quick to imitate successful items. The rents from innovations in organization and marketing or other process innovations tend to be more long lasting.

neglected (see next section), China has moved faster than any of its neighbors in laying the foundations of a world class system.

The Urban Dimension of Technology Development

S&T activities and industrialization are primarily urban phenomena and in East Asia, the most dynamic and fast growing industries have emerged in a relatively small number of cities. China's "opening and growth" since 1979 commenced with the establishment of 4 special economic zones privileged with incentives for export oriented industrialization which were subsequently extended in 1984 to 14 coastal cities and to several new coastal economic zones. These urban centers and regions triggered and have crucially sustained China's remarkable economic performance. They have served as the locus for integrated industrial clusters that share a common labor pool, facilitate buyer-supplier relationships, allow collaboration between firms to refine and develop technologies, and encourage joint efforts to create marketing, information gathering and training systems. Where cluster networking is taking root, it is internalizing technological spillovers and in the most successful cases, providing a virtuous balance between competition and cooperation. To foster clustering, cities are relying upon science parks, incubators and extension services, encouraging local universities to engage in research and to establish industrial linkages, inducing venture capitalists to invest in SMEs in the area, attracting a major anchor firm, local or foreign, that could trigger the in-migration of suppliers and imitators. Higher level governments have reinforced these initiatives with investment in infrastructure and urban services and through a variety of tax and financial incentives (see Yusuf, Nabeshima and Yamashita 2008).

Some industrial clusters as in Zhejiang⁶⁵ and Guangdong materialized autonomously from long established traditions of entrepreneurship and the strengths of local networks; others congealed mostly as a result of initiatives taken by national and

⁶⁵ See Huang, Zhang and Zhu (2008) on the footwear cluster of Wenzhou.

local governments⁶⁶. In many instances, the attempts to create cluster dynamics failed even after a number of firms established production facilities at an urban location – which reflects the experience of cities worldwide. That notwithstanding, dense urban-industrial agglomerations, some with networked clusters of firms have been vital for the growth of productivity, for technological change and for promoting further industrialization by opening opportunities and crowding in capital and skills.

Three major urban/industrial agglomerations – the Pearl River Delta region centered on Shenzhen, Dongguan, and Foshan, the Yangtze River region around the Shanghai-Suzhou axis and the Bohai region in the vicinity of Beijing and Tianjin – have spawned multiple clusters producing everything from toys, footwear and garments to computers, electronic components, autos and software⁶⁷. Further industrial deepening in these three regions is continuing and in addition industrial agglomerations are expanding in a number of the inland cities, such as Chengdu, Chongqing, Xi'an, Hefei, Wuhan, and Shenyang. Some clusters are evolving from industrial parks, such as the Zhongguancun IT cluster (Beijing), the Pudong Pharmaceutical cluster (Shanghai), and the Wuhan opto-electronics cluster (Hubei Province), but most clusters are still operating at the lower end of the industrial value chain, and lack horizontal integration (see Zeng 2010).

In spite of the rapid pace of industrial agglomeration nationwide, significant regional differentials remain between coastal and inland cities. Productivity (measured by the GDP output per labor force) of the East region is almost twice that in the Middle region and thrice that in the West region (see Annex Table 10). Scientific and technological advances measured by patenting, also are much higher in the coastal regions (Annex Table 11).

Technological capabilities and innovation would certainly benefit from a greater participation of major cities in the inland provinces, many of which have substantial

⁶⁶ Cluster development is characterized by a variety of typologies determined by country type, national policies and local business circumstances. See He and Fallah 2011; and Fleischer, Hu, McGuire and Zheng (2010) on the children's' garments cluster in Zhili township.

⁶⁷ See McGee and others (2007, esp. ch.6).

manufacturing capabilities, growing stocks of human capital and strong tertiary institutions. A two-pronged approach that stimulates innovation in coastal urban areas and cultivates it in the leading inland urban centers, would increase the likelihood of achieving growth objectives and also serve to reduce income and productivity gaps⁶⁸. Inland cities are in a position to capitalize on favorable wage and rental gradients and with suitable investment, some could offer more affordable housing, recreational amenities, and public services to attract knowledge workers and high tech firms. According to a recent study by McKinsey (2011), China's mid-sized cities with excellent growth prospects – such as Wuhan and Zhengzhou – would be contributing more to GDP growth than the leading coastal megacities.

III. The Road to Innovation: Assets and Speed Bumps

The imperative of building domestic innovative capacity is entwined with the dynamics of knowledge diffusion and the large rents which can accrue to lead innovators and first movers. Once a country is at the technological frontier and cost advantages have largely disappeared, producing and capitalizing on a steady stream of innovations provides a degree of assurance against economic stagnation. A compelling finding that has emerged from the analysis of patent data is that new knowledge diffuses very slowly from the point of origin which is invariably an urban center. A substantial body of research indicates that a few cities account for a high percentage of innovations and these cities share certain attributes that make them “sticky”⁶⁹ for knowledge networks and clusters. Much of this knowledge is tacit and uncodified and it spreads often through personal communication and contact among a small number of researchers⁷⁰. The circulation of new findings among firms in a cluster and between universities, research institutes and firms proceeds slowly and can take 3 years or more depending upon the nature of the technology, the type of firm, and expenditures by firms on R&D^{71 72 73}. The

⁶⁸ See Fan and Kanbur (2009) on regional income disparities and the measures employed to reduce them.

⁶⁹ See Markusen's (1996) views on factors contributing to stickiness in slippery space.

⁷⁰ Meisenzahl and Mokyr (2011) observe that the innovations responsible for the industrial revolution in Britain was the work of a small band of inventors and a limited contingent of skilled craftsmen who helped realize the industrial potential of the innovations. Lane (2009) observes that San Diego owes 40,000 jobs in the life science and 12,800 jobs in electronics to the research of just four scientists at the UC San Diego.

⁷¹ See Adams, Clemmons and Stephan (2006).

persistence of this tendency in spite of great advances in communications presents a strong case for investment on research to push the technological frontier and to grow innovations locally in ‘sticky’ cities. The challenge for China is to arrive at a national innovation strategy that is cost efficient, rationally sequenced and urban-centric.

Tailwinds and Headwinds

In its pursuit of innovation as a driver of growth, China starts out with seven advantages:

First is the scale and wide ranging capabilities of its manufacturing sector which is reaching the point where products can be reverse engineered and new product lines brought into large scale production within months. This is being aided by the co-location of R&D and manufacturing in China’s leading industrial centers provides the foundations of a robust innovation system. Advanced countries faced with a hollowing of their industrial sectors are rediscovering this complementarity: once manufacturing capacity is severely eroded, the skills and capabilities undergirding innovation are also imperiled⁷⁴.

Second, having expanded its education system, China’s efforts to innovate will be buoyed by the large supply of S&E skills, adequately meeting the demand for high level skills that is likely to remain strong unlike the case in Japan for example⁷⁵. Moreover, the increasing attention to the quality of schooling at all levels including the programs to develop world class universities⁷⁶ will reinforce the benefits from supply (See Yusuf and

⁷² Jaffe and Trajtenberg (1996) used patent citations to map the diffusion of knowledge. Others have observed that patents are only one of the avenues through which knowledge diffuses from universities. Certain informal means of communication are of greater importance. See Agrawal and Henderson (2002).

⁷³ Keller (2001a and 2001b) substantiates earlier work by Jaffe and by others.

⁷⁴ This was the message of a major study conducted in the late 1980s by a group from MIT (See Dertouzos and others 1989). It is echoed by “When Factories Vanish, So Can Innovators 2011”; emphasized by “Andy Grove: How America Can Create Jobs 2010”; and reflected in the recent report by the President’s Council of Advisors on Science and Technology *Report to the President on Ensuring American Leadership in Advanced Manufacturing*.

⁷⁵ See Nature (2011).

⁷⁶ The reforms underway to make Shanghai’s Jiao Tong University into a powerhouse comparable to MIT are described by Wang, Wang and Liu (2011). And the making of high caliber universities is explained in detail by Salmi (2010) and Altbach (2011). See also Kaiser (2010) on how MIT became what it is.

Nabeshima 2010). The results of the 2009 PISA tests⁷⁷ provided an inkling of what can be achieved through focused attention to raising quality of primary and secondary schools⁷⁸. Similar progress in the quality of tertiary level graduates nationwide would provide a quicker boost to innovativeness and productivity⁷⁹.

Third is the elastic supply of patient capital to support innovative firms – that are currently in need of risk capital and new entrants attempting to commercialize promising ideas. Venture funds and China’s private and state owned banks are meeting some of the demand especially in the coastal areas of the country but a gap in funding remains.

A fourth advantage derives from China’s successful penetration of the global market increasingly complemented by the expanding market of domestic urban middle class consumers⁸⁰. A large domestic market attracts MNCs and innovators, allows domestic producers to attain scale economies, and permits the formation of clusters and agglomerations. It tests and winnows products and services and rewards winners. China’s middle class is expected to double in the coming decade and double again in the next.⁸¹ Foreign firms first flocked to China because it was an attractive platform for low cost manufacturing. However, during the past decade, the widening domestic market has added to the appeal of investment in China for their existing product lines and for new offerings.

“Top Test Scores From Shanghai Stun Educators 2010”; Science (2010).

⁷⁸ Students from Shanghai topped the list with a score of 575 in science and 600 in mathematics, and although the scores from a single city are not representative, the results demonstrate the potential China can exploit through improved schooling on a nationwide scale. Among the measures introduced by Shanghai to raise the quality of education are merit pay for teachers demonstrating results as measured by test scores; the designing of a new curriculum to prepare students for tertiary level training; its mandating for all schools; and rigorous testing (Chinese Lessons for the U.S. 2011).

⁷⁹ See Hanushek (2009); and Pritchett and Viarengo (2010) who draw attention to the upper tail of the distribution of student test scores and their association with GDP growth rates.

⁸⁰ There is a great deal being written on the Chinese middle class consumers and even discounting for the hype, the potential is clearly on the rise. See Cheng Li (2010); and PWC (2007); McKinsey Quarterly (2008); Economist (February 14th 2009).

⁸¹ Michael Porter pointed to the importance of the domestic market in stimulating the competitiveness of firms. See Bhide (2009); and Yu Zhou (2008). In PPP terms private consumption per head in China was only a tenth of the average for OECD countries, however, about 50 million households had incomes that exceeded 30 percent of U.S. households. (OECD 2010).

Fifth is the pro-business, entrepreneurial culture (staunchly backed by local authorities) in several of China's provinces which is supportive of small firms and start-ups as is apparent in the Pearl River Delta, Zhejiang, Fujian and elsewhere. Entrepreneurship is not synonymous with innovativeness⁸² but it can become a precursor as ideas and opportunities multiply. State sector reforms initiated in 1996-7 led to the exit, privatization, restructuring and corporatization of thousands of state and collective enterprises and galvanized the private sector. Since then, there is ample evidence of entry and exit of private firms and of smaller and medium sized publicly owned firms under conditions of frequently intense competition local and foreign⁸³. This is conducive to innovation – initially most firms are focused on cost innovation and customization for the domestic market but that can change.

Sixth is the potential inherent in China's still underdeveloped and relatively unproductive services sector. The technology and productivity gaps in services are particularly large as are the opportunities for innovation. With the services sector expanding robustly and set to overhaul industry during the next decade, the low hanging fruit with regard to growth, productivity gains and employment are increasingly tilting towards the services, tradable and non-tradable. Among the thus far largely non tradable services such as education and healthcare, IT related and other advances in technology could lead to breakthrough outcomes. Indigenous innovations in marketing⁸⁴, online sales, after sales service, and in IT services, to name just a few, are already on the rise with many new firms entering the market. If the trend strengthens and it leads to the emergence of a few national giants as is happening in the U.S and Europe (with increasing MNC activity) and innovation intensifies, productivity gains in services could begin to equal or overshadow those arising from manufacturing⁸⁵.

⁸² This has been noted by De Mayer and Garg (2005) who write that, "An examination of many success stories of Chinese entrepreneurship reveals that in fact these are success stories about trading, exploiting information asymmetry and property land deals. There is nothing wrong with these activities, but they are rarely about value creation through innovation".

⁸³ This has resulted in corner cutting and environmentally damaging practices. See Midler (2011).

⁸⁴ This is where firms such as Lenovo have an advantage over foreign rivals such as Dell and HP and why foreign firms seeking to tap the Chinese market need by finding reliable and savvy Chinese partners.

⁸⁵ See Jorgenson, Ho and Samuels (2009) on the contribution to IT to productivity in services. Brynjolfsson and Saunders (2010) provide additional evidence.

Seventh, and finally, not only is China urbanizing but relatively early in the game, some Chinese cities are realizing that the productivity and growth of urban economies will rest upon the quality of life and on the resilience of cities which will be a function of urban design, the adequacy and efficiency of hard and soft infrastructures, environmental quality, affordable housing, and how effectively cities – or entire metro regions – are managed and decisions coordinated. Successful innovation will be a function of both national strategy and its elaboration and regional implementation (Howells 2005).

These several advantages are counterbalanced by a number of challenges and constraints:

First China's macroeconomic policies need to encourage the growth of the domestic market rather than focus industrial attention mainly on exports⁸⁶. An increase in domestic household consumption (currently accounting for a little over a third of GDP) will have a positive impact on indigenous innovation privileging the wants of Chinese buyers.

Second, China's SOEs are a conservative force, indifferently managed⁸⁷ and generally averse to adopting strategies that give primacy to growth through innovation. Even when they invest in R&D – which many are doing under pressure from the state – it tends to be unproductive and poorly integrated with the rest of their operations. Compared to smaller enterprises, the SOEs are not as efficient at converting resources into patents and innovations (Annex Tables 12 and 13 for the industrial sector and Annex Tables 14 and 15 for high tech industries only)⁸⁸. Extracting high returns from R&D

⁸⁶ This is not to deny the innovation stimulating effects of exports, which over the near term are likely to be greater than those of the domestic market. However, now that China is the world's largest exporter (and the leading manufacturer with 19.8 percent of global output in 2010 as against 19.4 percent for the U.S.), a slowing of export growth and the concomitant restructuring of production and demand will increase the salience of domestic consumption on growth and on innovation – possibly of a different sort.

⁸⁷ On the contribution of managerial competence and dynamism to productivity and profitability, see Bloom and others 2010; and Bloom, Sadun and van Reenen 2009.

⁸⁸ Although SOEs are less efficient users of R&D resources, they have a higher ratio of invention patents to total patent applications.

requires managerial ingenuity and experimentation with organizational structures, incentives and an integration of research, production and marketing activities.

Third, China's universities particularly the leading ones, are adding capacity and giving greater attention to research and its commercialization, but the procedures for recruiting faculty with superior qualifications from domestic and international sources⁸⁹ could be improved, and many university faculty members need more experience. Moreover, the quality of research is low, there are worries that faculty in the leading research universities are distracted from attention to teaching by the importance and financial rewards from consulting and those associated with publication and patenting. There are also widespread concerns over research ethics⁹⁰ and the rigor of peer review of publications and projects. There is too much pressure on researchers to produce and collectively raise China's standing in the world, and it is leading to dysfunctional outcomes. The scarcity of talented young researchers is also an issue confronting universities as they attempt to recruit individuals with foreign PhDs and/or overseas experience. There is a tendency to tenure full professors from overseas institutions, but this tends to encourage others to spend their most productive years abroad (Science, 2011, p.834)

Fourth China's venture capital (VC) industry is relatively inexperienced as are other providers of services to start-ups and growing high tech firms. Moreover, even with the emergence of local private VCs and the entry of foreign VCs, the industry remains dominated by the public sector (Zhang and others 2009). This is being corrected, but in

⁸⁹ Recruitment of Chinese and foreign faculty members from overseas to introduce higher quality talent and introduce greater diversity is ongoing with the offer of generous incentives however, the attempts to do so are producing limited results and encountering resistance domestically. See Science (2011) and the efforts by Shenzhen University <http://topics.scmp.com/news/china-news-watch/article/Shenzhen-University-in-global-search-for-top-talent>

⁹⁰ Plagiarism is a serious issue and one commented on in leading foreign publications. <http://factsanddetails.com/china.php?itemid=1651&catid=13&subcatid=82>; <http://www.npr.org/2011/08/03/138937778/plagiarism-plague-hinders-chinas-scientific-ambition>; <http://www.nytimes.com/2010/10/07/world/asia/07fraud.html>

the meantime entrepreneurs continue to lack the mentoring, professional assistance, networking links and market insights which are invaluable for young firms⁹¹.

Fifth, Chinese firms need to work closely with MNCs to build innovation capabilities and it is in the interests of both parties to create a robust innovation infrastructure. But MNCs may hesitate if they have to worry about IP protection, exclusion from government contracts, newly introduced indigenous standards, rising domestic content requirements, and pressure to transfer technology to China in exchange for market access⁹². Innovation policies need to establish greater trust between the government and foreign investors and stronger institutions that validate and operationalize the mutuality of interests.

Sixth although the benefits of smart urbanization are becoming apparent to many, much urbanization in China is proceeding inefficiently and untidily – sprawl, ribbon development along new highways, real estate speculation, rising costs of housing, and neglect of long term urban financing needs. These tend to hinder productivity, make it harder for cities to support an ecosystem of small businesses that can form the lifeblood of urban economies and a major source of innovation⁹³. Furthermore, the absence of longer term fiscal planning jeopardizes urban sustainability.

Seventh, the signature characteristic of innovative economies is a learning and research environment encouraging new ideas and lateral thinking, and a reliance on market signals to guide the direction of innovation with the public sector playing a facilitating role, seeding experimental research with a long term pay-off, providing the legal and regulatory institutional scaffolding and establishing enforceable standards. China is some distance from this model of an open, cosmopolitan, market-directed innovation system. It may well be that the *dirigiste* approach adopted by the Chinese state could deliver the goods with respect to innovation as it appears to be doing with

⁹¹ See for example the model for mentoring start-ups introduced by Paul Graham the founder of Y Combinator “The Start-up Guru 2009”.

⁹² See Hout and Ghemawat (2010).

⁹³ See Glaeser (2011).

technological catch-up. China is putting fairly big bets on a number of technologies even as an innovation system is being pieced together, and without thoroughly evaluating the returns from R&D spending or the merits of recent policies to spur innovation⁹⁴. The development of science and technology for the purposes of innovation remains a planned activity on an expanding scale spanning multiple sectors with a lot at stake and considerable uncertainty regarding the future productivity gains.

The time for a hard look at innovation strategy and policies is now.

IV. A Policy Menu

China is embarked on a longer term strategy aimed at achieving technological parity with the advanced countries, and deriving more of its growth impetus from higher productivity across the spectrum of activities and by capitalizing on the commercial benefits from pushing the technology frontier in selected areas⁹⁵. This transformation is likely to occur in two stages which will require a varying of the policy focus between the first stage and the next. In the first stage (2011-2020), China will continue to benefit from imported technologies supplemented by domestic incremental innovation, to increase productivity and deliver rapid economic growth. An emphasis on building market institutions to strengthen competition and facilitate the entry of SMEs, on the quality of the workforce, on encouraging applied research in firms, and on further reforming SOEs, may be appropriate.

In the second decade (2021-2030), China will have to rely more on indigenous innovations requiring not just the generation of ideas through cutting edge basic research – with blue skies research supported by the state – but also the harnessing of these ideas by dynamic Chinese multi-national private firms which are technology leaders in their own particular areas and engage in high levels of research.

⁹⁴ See the suggestions in Lane and Bertuzzi (2011)

⁹⁵ A comprehensive treatment of innovation policy can be found in World Bank (2010).

As we indicate earlier in the chapter, policies for the first stage necessarily overlap with second. The difference is in emphasis. The policies listed below are frontloaded because the building of the innovation ecosystem is concentrated in the balance of the decade with the government playing a lead role. In the second stage, the burden of success will rest on the business sector, which is why the creating of a competitive business sector is of the greatest importance. National technology and innovation policies will need to be complemented by urban policies that recognize the vital role of cities in advancing ideas and technologies. The roles of the various entities involved are further spelled out in Annex Tables 16.

1. A competitive market environment is necessary condition for steady improvement in productivity. This entails the opening of product markets, and the fair and effective enforcement of laws regulating competition and protecting intellectual property as well as consumer rights. It also extends to competition and ease of mobility in factor markets⁹⁶. Starting in the late 1980s, for example, market oriented reforms stimulated entry and competition in most manufacturing sub-sectors. Even in some “strategic” or “pillar” industries (for example, airlines and telecommunications) the breaking up and corporatization of incumbent providers in 1990s released additional competitive pressures. More recently, the phasing out of tax incentives which had favored foreign investors stimulated competition by leveling the playing field with domestically-owned firms. China’s WTO accession in 2001 increased competition from imports and the large volume of FDI has led to a further intensification of competitive pressures. Sustaining this trend through institutional reforms and measures to enhance the supply of risk capital as well as the mobility of the workforce, will be critical to the making of an innovative economy. They will stimulate the deepening of the private sector, reduce barriers to firm entry and exit, promote the growth of dynamic SMEs, induce the SOEs to raise their game (and pave the way for further reform), and result in national market integration as well as much needed regional or local specialization of industry.

⁹⁶ On issues relating to competitiveness and competition policies see De Grauwe (2010) and Oster (1999).

2. The government can enhance the incentives to innovate countrywide by taking steps to further increase the integration of the national economy, discourage local protectionism and coordinate R&D activities at least by public entities – including universities - so to minimize the duplication of sub-optimally scaled research and the waste of resources it entails. This would include intensifying the degree of competition and churning among firms⁹⁷, encouraging firms to compete on the basis of technology, and promoting much needed regional or local industrial and research specialization. Appropriately pricing fossil fuels, electricity and other non renewable resources, the setting of national standards (including environmental standards and standards encouraging energy efficiency) for products and the enforcement of these standards would also generate pressures to upgrade technologies which some western countries have done to good effect⁹⁸. Meeting these standards by smaller firms would be facilitated by strengthening the industrial extension system and providing smaller firms with easier access to laboratory, metrology, testing and certification facilities. The German Fraunhofer Institutes and the TEFT system in Norway provide models for China to adapt. In Japan, the TAMA association makes available to its member firms, most of which are of small and medium sizes, laboratory facilities and testing equipment plus other services.

3. The central government can take greater initiative in building country wide research networks that mobilize national talent and reduce the relative isolation of inland cities by including firms from the inland cities in research consortia⁹⁹ tasked with disseminating the latest technologies and advancing technology in areas where they have an existing or nascent comparative advantage¹⁰⁰. Such consortia have been sponsored by governments in Japan and the U.S. and they can help China develop more “global challengers”

⁹⁷ The gains from churning and creative destruction are analyzed by Fogel, Morck and Yeung (2008); Liang, McLean and Zhao 2011; and Bartelsman, Haltiwanger and Scarpetta 2004.

⁹⁸ Popp (2010) shows how environmental regulation and standards have contributed to green innovation.

⁹⁹ See Mathews (2000) on the formation and working of consortia in Taiwan (China); and Branstetter and Sakakibara (1998); and Dodgson and Sakakibara (2003) on the utility of consortia in Japan and elsewhere in Asia.

¹⁰⁰ The OECD report on S&T in China (2007, p.2) comments on the “islands” of science in China and urges the linking together of these islands; “the gates of thousands of science and technology parks [need to be] opened up through the promotion of networks for sharing human and capital resources. A greater national and regional concordance would avoid wasteful research duplication such as by issuing guidelines or creating an independent coordinating agency”.

including from the inland metro regions. Successful regional innovation systems are associated with a mix of smaller firms that often take the lead in introducing new technologies and larger firms with resources to perfect, scale up, and improve and market the commercial outcomes of these technologies. Recognizing the cost and complexity of research in frontier fields (especially green technologies); even the largest firms are finding it desirable to specialize and to form partnerships with other firms or with universities when developing sophisticated new products or technologies. Through a pairing of inland firms with more advanced firms from the coastal cities (including MNCs), the research potential of the interior would be more fully exploited and technological capabilities enhanced. In addition to consortia, the technological and innovative capabilities of inland cities would benefit if both domestic and foreign firms could be persuaded to locate some of their R&D centers in these cities, and not just production facilities, a process already underway in Chengdu and Xian for example¹⁰¹ but one that will hinge on urban development policies.

4. The quality of Chinese universities needs improving. China's universities are graduating millions of students each year to meet the needs of the knowledge economy¹⁰². An estimated 6.3 million including more than 50,000 with doctorates entered the job market in 2010 – But the quality of the training is weak and many graduates are having difficulty finding employment, although this is likely to be temporary¹⁰³. The low quality is explained by four factors: the massive expansion of enrollment which has strained instructional capacity; the short duration of PhD training (3 years); the inexperience and weak qualifications of instructors; and university systems poorly equipped to exercise quality control and to weed out the weaker candidates (Nature 2011, p.277). In the meantime, employers complain of a serious shortage of highly skilled technicians, engineers and executives. This low-skill glut and high-skill shortage poses a difficulty for the skill transfer needed for companies to improve the quality of their

¹⁰¹ Both house military research and production facilities. Chengdu is one of China's four space research centers and produces military jet planes.

¹⁰² Zhang and Zhang (2011) find that tertiary education has a stronger impact on growth than primary or secondary education.

¹⁰³ "China's Army of Graduates Struggles for Jobs 2010"

output, or move to a higher rung of the value chain. As the demand for tertiary education is likely to keep rising and quality will remain a major issue, China's universities will have to consider some disruptive innovations¹⁰⁴ of their own in order to provide customized education for a vastly larger body of students at an acceptable cost¹⁰⁵. This they are more likely to do if they enjoy a measure of autonomy with respect to governance, modes of instruction, curriculum design, hiring, salaries, course offerings and research orientation; are induced to compete and collaborate with universities throughout the country; and supplement traditional lecture based training by using online and IT tools and new pedagogical practices. Universities will need to recruit faculty from among some of China's brightest graduates many of whom will be inclined to pursue careers other than teaching¹⁰⁶, to tailor course offerings, instruction and research, to so as to efficiently deliver quality services to a varied student body and succeed in instilling a mix of technical and soft skills (communication, team working, report and business plan writing) as well as industry knowhow in greatest demand. Perhaps the greatest challenge is how to encourage creativity and initiative, attributes which are urgently needed as the country strives after technological maturity¹⁰⁷.

By harnessing IT and tapping the expertise and resources of leading firms, universities can improve teaching, motivate students to stick with demanding courses, limit the escalation of costs (which is crippling schools in many advanced countries)¹⁰⁸, and help equip universities with the infrastructure they need to fulfill their missions. China's front ranked schools must also be able to mobilize the funding and staff faculty positions to offer cross disciplinary post graduate and post doctoral programs¹⁰⁹ and set

¹⁰⁴ See Christensen, Horn and Soares (2011).

¹⁰⁵ See for example, Zhong (2011).

¹⁰⁶ Persuading a significant percentage of the best graduates and PhDs to take up teaching is key to achieving quality but unless teaching is seen as rewarding monetarily and otherwise, only a small minority can be persuaded. (McKinsey 2010).

¹⁰⁷ This is a view widely shared by policymakers in South-east Asian countries as well.

¹⁰⁸ Steeply rising costs of education in the US and a decline in the analytic, reasoning writing and other skills imparted to students by all about the leading selective colleges and universities, is a cause of worry and a lesson for other countries which could face similar trends. The changing culture of learning, the attitudes of students, wasteful practices of colleges, and distorted incentives for faculty all share the blame. See Arum and Roksa (2011); Hacker and Dreifus 2010; and Taylor 2010.

¹⁰⁹ Some Chinese universities are increasing their cross disciplinary offerings by hiring foreign faculty members with the requisite experience. "Foreign Researchers begin to make their mark" 2011.

up specialized, well staffed research institutes. The quality of the faculty will also influence the degree and fruitfulness of university industry collaboration¹¹⁰.

The process of transforming universities in China could be accelerated by inducing some of the world's greatest universities – such as Harvard and Cambridge to establish branch campuses in China as INSEAD has done in Singapore. Designating a “special university city” would be one way attracting the most selective schools and giving them full autonomy to conduct their activities without violating Chinese laws.

An important contribution universities can make to innovation is by generating ideas and serving as a breeding ground for entrepreneurs¹¹¹ and skilled researchers who are the vehicles for transforming ideas into commercial products and services. Together the government and universities can enhance the dynamism and innovativeness of the private business sector.

5. The development of high tech industry envisaged by the 12 FYP depends upon a vast range of technical skills to staff factories, render IT support, maintain and repair complex equipment and provide myriad other inputs and services. Smaller firms and start-ups frequently have difficulty finding such skills and can rarely afford to provide much training in-house. Hence public -private initiatives to secure and replenish the base of technical skills essential for a smart city can anticipate market failures and promote desirable forms of industrial activity aside from minimizing both frictional and structural unemployment. Labor market institutions can be strengthened and made non discriminatory by setting up multilevel professional advisory agencies and increasing the provision of vocational training for which there would be a demand from expanding and new enterprises. In the most innovative and industrially dynamic European countries such as Germany, Switzerland and Finland, between a quarter and one half of all secondary school students take the vocational and technical route to a career in industry rather than

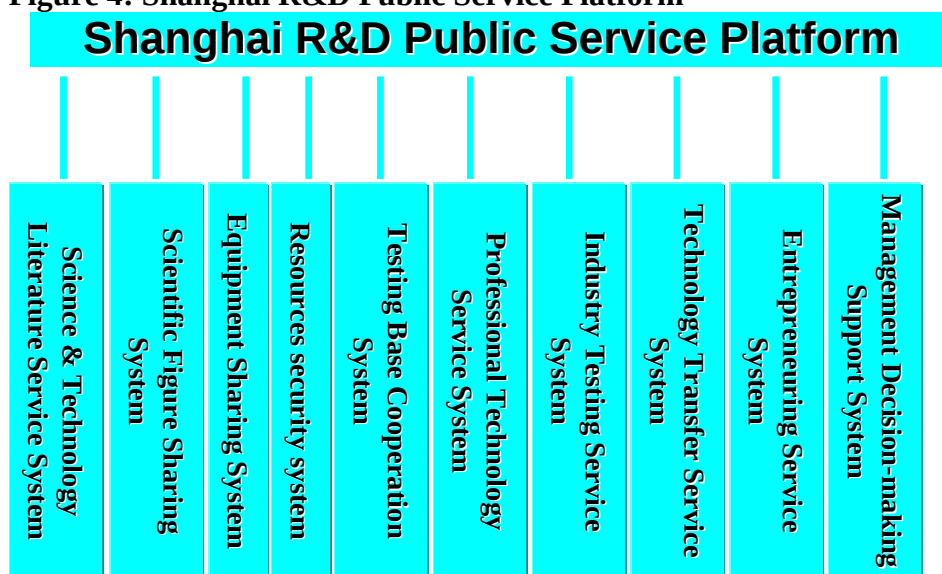
¹¹⁰ Perkman, King and Pavelin (2011).

¹¹¹ Experienced venture capitalists are more likely to “bet on the jockey and not on the horse” and to want to know how many PhDs a high tech start-up has on its payroll.

opting for general education. Striking a better balance between the general and the technical would seem to be warranted.

In China, there is a range of VTEC and business service providers such as engineering research centers and productivity centers, but many of them lack the market orientation and suffer from funding and skills shortages. It is important to make them more functional and more responsive to the needs of the economy through a public-private partnership approach. However, there are some good examples which can be more widely replicated. Figure 4 illustrates the example of Shanghai's R&D public service platform which offers a wide range of business and extension services. These services cover the innovation development process from sharing of scientific information to technology testing and transfer services to support for entrepreneurship and management.

Figure 4: Shanghai R&D Public Service Platform



Source: Shanghai Municipality Science and Technology Commission (2006), "The Innovation System of Shanghai", presentation made to an OECD delegation in Shanghai, China, October 9, 2006.

6. Many high tech multinational corporations have invested in R&D facilities in China. This should be further encouraged and facilitated because of its potentially significant spillover effects arising from the knowledge and experience imparted to the Chinese

workforce, the reputational gains for Chinese cities which will come to be seen as science hubs, and the contribution such research can make to industrial upgrading. Closer collaboration and partnerships with MNCs¹¹² on the basis of mutual trust and recognition of the interests of both parties will contribute greatly to the creation of a dynamic and open innovation system¹¹³. The size and future growth of China's market means that many MNCs will be shifting the primary focus of their operations to China and as a consequence, technological spillovers are very likely to increase. In this context, an efficient patenting system that reflects the experience of the U.S. and European systems (both of which are in the throes of reform)¹¹⁴ and effective protection of IP will expedite the growth of China's innovation capabilities (de Vaal and Smeets 2011). Gwynne (2010, p.27)¹¹⁵ writes that, "Even companies that possess legitimate Chinese patents have had problems defending their rights ..because the scope for protection is much narrower And when it comes to enforcement, only [recently] have there been any large damage awards for infringement"

Most of the applied research and innovation of consequence for the economy is done by firms¹¹⁶ – in the U.S. for example the vast majority of scientists are employed by businesses and governments and not by institutions of higher learning. Innovation will flourish if firms in particular provide researchers with the freedom and stimulating work

¹¹² Highly successful and innovative companies such as Cisco eagerly pursue open innovation.. In fact, according to Branscomb (2008, p.916), "Cisco's most important innovation is its partnership with customers and competitors, making it a true networked enterprise. Li and Fung maximize the collective innovative capacity of dozens of partners needed for a specific product by orchestrating them into a remarkably flexible, agile and skilled collaborative supply chain. They mix and match the special technical skills of the partners, creating a network enterprise".

¹¹³ Collaboration needs to be encouraged at several levels. Changhui Peng (2011, p.267) writes of the increasing necessity of collaboration among scientists and observes that in order to catch-up, China should be a more active participant on bodies such as the IPCC and FLUXNET (the global network of micrometeorological tower sites. <http://www.nature.com/news/2011/110720/full/475267a.html>)

¹¹⁴ On the problems which the U.S. Patent office is attempting to resolve see "U.S. sets" (2011); and the European system see de la Potterie (2010)

¹¹⁵ "The China Question" (2011).

¹¹⁶ The share of R&D expenditures by firms increased from 68 percent in 2005 to 74 percent in 2009. This led to a decline in the share of expenditures by R&D institutions from 21 percent in 2005 to 16.5 percent in 2009 (see Table A19). Hence, even though increase in proportion of R&D performed by business enterprises is interpreted as a desirable characteristic of a country that wants to become more innovative (Mani 2010), this trend in China is partly an outcome of its S&T policy of converting R&D institutes into business enterprises.

environment to pursue interesting ideas (Shapin 2010)¹¹⁷. Mani (2010) notes that, “[D]ue to various historical and structural reasons, the efficiency and innovation capacity of the business sector is still insufficient, despite a large and rapid increase in scale and scope” (pp. 15-16). Mani uses a crude measure of firms’ ability to develop local technological capabilities as the ratio of intramural R&D in business enterprises to cost incurred in technology purchases from abroad. Over 1991-2002, China’s average propensity to adapt grew from less than unity to only about 1.5 in 2002.

The influx of FDI and the recent brain gain is helping to enhance managerial experience as well as technical, research and teaching skills but a significant shortfall persists¹¹⁸. To move forward, both the private sector and the government need to invest more in improving human resources and especially management in state owned and private enterprises¹¹⁹. Too many Chinese senior managers from companies with global ambitions lack formal management training and most are deficient in English language skills. They tend to rely more on informal networks to gather information and on intuition and instincts in making decisions. As a consequence, firm level research and innovation strategies can be haphazard and not systematically engage the relevant departments of a firm¹²⁰, little effort is made to gather and analyze data to evaluate results and to guide decisions, and interaction with foreign firms – including foreign travel – can be delegated to junior staff. Absent improvements in management, China may struggle to absorb

¹¹⁷ Lane (2009, p.1274-5) remarks that, “Science investment needs to generate an “aha” moment or an idea that has value. Translating that “aha” moment into an innovation also requires a well functioning team or organization, a well functioning patent system, a well developed firm ecosystem, or appropriate university links to industry”. In this context, the research and innovation strategies of Chinese firms and what they can learn from successful firms in advanced countries are of importance. See Annex C for some findings on approaches to innovation by Chinese and Japanese firms. A number of Chinese case studies are presented by Tan (2011). Other case studies of foreign firms can be found in Herstatt and others (2006); and Boutellier and others (2000).

¹¹⁸ Active recruiting of overseas ethnic Chinese academics and researchers is leading to a brain gain for China and helping to improve the caliber of faculties and of research. However, less than 30 percent of those going abroad return and very often the ones who do are not the leading lights. Nevertheless, the relative attractiveness and rewards to working in China have increased steadily and the trend in brain gain seems to be positive. See “China: Returnees are critical in innovation push”, 2011; “China’s reverse brain drain, 2009; “Rise in scientists returning to China”, 2011.

¹¹⁹ Some recent research on enterprise restructuring in China can be found in Oi (2011).

¹²⁰ This is a practice perfected by the leading Japanese firms, which along with attention to customer feedback, accounts for their efficient commercialization of innovations.

technology¹²¹ at the desired pace and make the leap from catch-up to a regime of steady innovation.

7. Central and provincial governments in China are seeking to enlarge the share of basic research¹²² in universities and research institutes as well as to raise the tempo of research in firms thereby building research capacity throughout the country. They are more likely to succeed through well targeted incentives, by committing a sufficient volume of funding, and by ensuring the continuity of funding. The NIH in the U.S. played the central role in the boom in the life sciences because it was and is a source of large and stable funding much of it for basic research done in the universities. This funding financed countless research programs, trained thousands of PhDs, supported post docs and created the depth of expertise which has enabled the U.S. to become the leader in the field of biotech. TEKES and SITRA in Finland have also contributed along similar lines. To maximize the spillovers from the government sponsored research and contests to develop particular types of technologies, one possibility would be to make the findings of this research widely available. In the 1950s and 1960s, the research on electronics financed by the U.S. government was shared generously and this enabled many companies to come up to speed and become innovators themselves. Even if China is able to raise R&D spending to 2.2 percent of GDP by 2020 as the government proposes, this is unlikely to have more than a minimal impact on productivity. Comin (2004) estimates that in the postwar period, R&D contributed between 3 and 5 tenths of a percentage point to productivity growth in the U.S. That high R&D has a limited effect on growth is also apparent from the experience of Sweden, Finland and Japan (see Lane 2009; Ejermo, Kander and Henning 2011). As Lane observes (2009, p.1274), “The relation between science and innovation is nonlinear in nature , with complex outcomes that can vary

¹²¹ Writing on technology absorption by SOEs, Li (2011) finds that own R&D is critical for the absorbing of technology – a point underscored by Cohen and Levinthal (1990) – and that SOEs find it easier to absorb domestically generated technology than foreign technology, which might be related to the degree of sophistication, ease of communication, and proximity to the actual research source. This does strengthen the case for indigenous innovation alongside international collaboration and borrowing from abroad.

¹²² The desirability of raising the share of basic research (only 5.2 percent of R&D spending in 2006 as against 10-20 percent in OECD countries) was noted by the OECD report on China’s S&T system (OECD Innovation Policy review 2008). Since then, basic research has received higher priority. See Zhu and Gong (2008); and Nature Publishing Index (2010, p.5).

substantially by discipline and is subject to considerable time lags...Innovation is nonlinear because the demand side and the supply side of ideas are inextricably intertwined". Clearly a one percentage point of GDP increase in R&D will be only one small strand of China's growth strategy.

8. Good research is inseparable from a stringent and disciplined process of refereeing and evaluation of research findings. This is something where the research community needs to take the initiative, particularly in strengthening research ethics¹²³ and instituting strict penalties against plagiarism; however, the government could provide some of the parameters and adopt a different approach to high risk research (as is the case with NIH's Pioneer and New Innovator Awards, and the Department of Energy's ARPA-E program) which promise to break new ground. Such projects should be evaluated by their potential for transforming a subfield. Universities can also take the lead in thickening the scientific culture of their cities by promoting public lectures, exhibitions, and contributing to the teaching of science in local schools.

9. Although the supply of risk capital has risen in China (and all middle income countries) demand has increased even more. The Chinese government is active in promoting both public and private venture capital at least in the coastal cities. Although some public risk capital is available in the inland cities, private venture capital for smaller private firms which are trying to scale up, is still scarce. However, the level of professionalism and experience of venture capitalists and the degree of trust between providers of risk capital and borrowers is still fairly low, hence further development of risk financing by VCs and business angels will be needed. Banks can serve as a partial substitute but such lending is rarely their forte. However, such lending on a limited scale by local banks to local firms and the creation of bank-led relational networks is a mode of financing that seems to work in the U.K. and the U.S. and complements the own resources of entrepreneurs, angel investors and VCs. Too little bank financing in China

¹²³ Greenberg (2007) points out that maintaining an ethical balance becomes even more important when universities draw closer to the business community and enter into many stranded research relationships. Troubling ethical issues have arisen in the US as a result of corporate sponsorship of medical and pharmaceutical research.

goes to private firms and especially the riskier high tech ones (see Hanley, Liu and Vaona 2011). That said the Dot.Com bubble and other bubbles have highlighted the waste arising from bouts of irrational exuberance fed by an excess of risk capital. The enormous investment in speculative real estate in China and in countries with sophisticated financial systems suggests that capital is not necessarily the constraint, more often it is investors who are rightly skeptical of technological offerings with uncertain prospects.

10. There is scope for making better use of demand-side instruments such as government procurement and the setting of standards for equipment and services. This combined with adequate efforts to guard against protectionist and rent seeking activities that undermine market competition, will go a long way to encourage the demand for innovation. Managing government procurement is a relatively new domain of policy in China. The first national guideline for government procurement was issued in 1999, and the Law was adopted by the National People's Congress in 2002. Despite the relative newness of this approach, the government's determination to support innovation through procurement has been clear. However, the procurement policy can be a double-edged sword. The key to success lies in open competition. In China, some potential risks in this area needs to be carefully addressed: (a) the risk of turning the government procurement instrument into one that protects national and local products from international and national competition; (b) the challenge of flexibly interpreting the official procedures for identifying "indigenous innovation products"; and (c) the risk of the government becoming a passive taker of what domestic suppliers offer, rather than a demanding buyer of technologically sophisticated products.¹²⁴ The demand for innovation could be increased through government standard setting. Standard setting allows governments and other entities to generate demand for advances in, for example, the performance, safety, energy efficiency, and environmental impact of products. To generate more demand for innovation, certain measures could be taken: (a) focusing exclusively on product improvement and resisting the tendency to use standard setting to protect or help domestic or local industry; (b) taking EU or US standards as a technical starting point while looking for ways to advance product performance; (c) involving industry leaders

¹²⁴ Zhang, Mako and Seward (2008).

more in standard-setting but this needs to be done in a productive way; and (d) changing the role of government from sole standard setter to time-sensitive driver of industrial consensus.¹²⁵

Innovation: The Role of Cities

Investment in technological capacity is more likely to result in a flourishing of innovation in a competitive environment and in “open” cities¹²⁶. Learning from its experience with rapid industrialization in the 1980s, China initially focused its efforts at developing technology with the help of FDI, imported equipment embodying new techniques, licensing and reverse engineering on a small number of the coastal cities, Beijing, Shanghai, Shenzhen, Guangzhou and Tianjin being among the leading ones. The decentralized urban-centered approach bolstered by suitable organizational and fiscal incentives, increased R&D, jumpstarted technology assimilation from abroad and created the framework for stimulating indigenous technology development. On the technological plane, these cities are performing the functions of the special economic zones in the 1980s. The proposed intensification of R&D activities during 2011-2020 and the increasing emphasis on achieving technological parity with the West, offers an opportunity to harness the potential of other cities and in the process, increase the productivity of R&D expenditures. International experience has shown that while the volume of R&D spending is a key determinant of innovation, the efficiency of R&D and the modes for exploiting findings so as to maximize the commercial payoff are at least as important. Both Sweden and Finland devote more than 3 percent of GDP to research, but Sweden is less effective in utilizing the results produced¹²⁷.

Industrial cities are in a separate class from innovative cities that can sustain innovation in the future. In these cities depth and quality of human capital is critical. These cities require institutional mechanisms and basic research of a high order for generating ideas and ways of debating, testing and perfecting these ideas and

¹²⁵ Ibid.

¹²⁶ See also Hu (2011, p.97)

¹²⁷ See Ejermo, Kander and Henning (2011).

transforming them into marketable products. The innovative city can achieve rapid and sustainable growth of industry by bringing together and fully harnessing four forms of intelligence: the human intelligence inherent in local knowledge networks of which research universities are a vital part; the collective intelligence of institutions that support innovation through a variety of channels; the production intelligence of a diversified industrial base that is a source of urbanization economies; and the collective intelligence that can be derived from the effective use of digital networks and online services, and face to face contacts in a conducive urban environment (Komninos 2008). Cities positioning themselves to become innovative hotspots are open to ideas and thrive on the heterogeneity of knowledge workers drawn from all over the country – and the world¹²⁸. Moreover such cities are closely integrated with other global centers of research and technology development and their teaching and research institutions must compete with the best for talent and to validate their own ideas. Last but not least, because innovative cities are at the leading edge of the knowledge economy, their design, physical assets, attributes and governance need to reflect their edge over others. Industrial cities can become innovative cities and in fact, a strong manufacturing base can be an asset as it is for Tokyo, Stuttgart, Munich, Seoul, Seattle, and Toulouse. But industry is not a necessary condition: Cambridge (UK), Helsinki, San Francisco, and Kyoto are not industrial cities, they are innovative cities that have acquired significant production capabilities that are Hi-tech or I-tech. Nevertheless, size is among the characteristics of innovative cities¹²⁹.

When it comes to defining a growth strategy that leverages urban innovation capabilities, quality and productivity trump sheer numbers. It is not how many patents, papers, technologies and new products that matter, rather it is the numbers of the really good and profitable ones, the ability to sustain innovation over decades and to flexibly enter new fields as existing ones become subject to diminishing returns. Picking tomorrow's innovative cities is both easy and difficult. The easy part is identifying cities that are already demonstrating their innovativeness and need to smarten up their act. The

¹²⁸ The advantages of diversity are convincingly presented by Scott Page (2007).

¹²⁹ Carlino, Chatterjee and Hunt (2007); and Carlino and Hunt (2009).

hard part is identifying the future performers from a long list. Below we touch upon some of the attributes of innovative cities, but perhaps the more difficult question is: what should governments do once promising candidates have been singled out?

Is becoming innovative all about human capital? Size and location are not decisive but they can be if they are combined with human and capital assets that are brought to par with the best in the world. In this context, four attributes stand out. First, intelligent cities have a high ratio of S&T workers in the labor force. A similar classification is available for China and other countries. Second, these cities host a number of universities and tertiary level enrollment is well above the average for the nation. Third, the industrial composition of the city favors industries employing large numbers of S&T workers with high rates of patenting. Fourth, intelligent cities usually attract one or a few major firms drawn from dynamic industries, which invest heavily in R&D and rely on innovation to maintain competitiveness.

A city that is top ranked with respect to high-tech and I-tech scores is Seattle, the home of Boeing and also of Microsoft. The composition of employment in Seattle by subsector, favors activities notable for their technology intensity such as aircraft and measuring instruments, and for IT intensity such as insurance, computer programming and architectural services. Innovative cities are also likely to fulfill the criteria of livability such as environmental quality, public services, recreational amenities, housing and connectivity. Seattle for example is one of the better run and most livable cities in the U.S. with an attractive coastal location.

Harnessing urban innovation nationwide

Cities become innovative because existing industries or institutions help to nucleate new activities and start a chain reaction. The process can be initiated by any of a number of catalysts. Decisive and visionary leadership by leading stakeholders; the upgrading and transformation of a local university; the creation of a new research institution; the arrival or growth of a major firm; a small cluster of dynamic start-ups; or

some other catalytic event that energizes a combination of intellectual and productive activities. There are virtually no instances in the past two decades of innovative cities being successfully made to order anywhere in the world. The attempts to engineer science cities such as in Tsukuba in Japan and Daejeon in Korea as well as other *technopoles* in Europe have rarely lived up to expectations.

For innovative cities, openness and connectivity are more important than scale. These contribute to the productivity of research and the generation as well as the testing of ideas. However, urbanization economies arising from size and industrial diversity can confer important benefits by providing a mix of technologies and production expertise out of which innovations can arise and which provide the soil for new entrants to take root¹³⁰. Connectivity via state of the art telecommunications and transport infrastructure (airports in particular)¹³¹ is a source of virtual agglomeration for an intelligent city which confers the advantages of a large urban center without the attendant disadvantages of congestion and pollution. In this respect, the smaller innovative cities of Europe and the U.S. enjoy the advantages of livability without sacrificing the productivity gains accruing from agglomeration.

To exploit the innovation potential inherent in virtual agglomeration, innovative cities need to actively network with other centers throughout the region and the world and build areas of expertise. This calls for embracing a culture of openness, and activism on the part of major local firms and universities to translate such a culture into commercial and scientific linkages that span the globe. However, to be recognized as an innovation hotspot, one or a few local firms must join the ranks of the world's leading companies in a technologically dynamic field and account for a sizable share of the global market.

The S&T capacity of China's coastal cities is well established and being steadily augmented through rising investment in the research infrastructure; that of several inland cities is now being developed through increasing attention to regional innovation policies.

¹³⁰ See for instance Henderson (2003); and Henderson (2010)

¹³¹ See Kasarda and Lindsay (2011)

Cities such as Xi'an, Chengdu, Zhengzhou, Hefei and others are attempting to raise the profile of their leading universities, grooming local firms that could become industrial anchors for local clusters, much like ARM¹³² and Cambridge Consultants served as the anchors for the electronics cluster in Cambridge U.K.. Several cities such as Chengdu, Shenyang and Chongqing¹³³ have also been successful in persuading MNCs to set up production facilities which augment manufacturing capabilities and create the preconditions for a concentration of the value chain.¹³⁴ Moreover, the leading inland cities are investing in the transport infrastructure to improve connectivity and all have established industrial parks to provide space and services for industry to grow. These plus a full suite of incentives satisfy most of the preconditions for the emergence of innovative industrial clusters. What might be missing is focus and the quality of the environment. The inland cities want to develop several of the industries designated as hi-tech. For example, electronics, autos, motorbikes, biotech, renewable energy and advanced materials are on the shopping list of all cities vying to become the intelligent cities of tomorrow. All the cities are attempting to upgrade local industries so as to move 'up the value chain' and seeking to link this with a localization of the innovation value chain as well – whether this will pay-off if they do so collectively, is doubtful¹³⁵. All are aiming to increase local value added so as to maximize well paid jobs and grow the urban revenue base. Although this sets the stage for intense competition (which can discourage innovation by increasing risks and reducing rents), it also could lead to a waste of resources as cities bid for a limited pool of talent, offer generous incentives to attract domestic and international companies, and protect local producers in an effort to deepen technological capabilities.

¹³² ARM (Advanced RISC Machines) was established in 1990 as a joint venture between Acorn Computers, Apple Inc, and VLSI Technologies. It is the leading producer of microprocessors for mobile telecommunications.

¹³³ Chongqing, in particular has demonstrated great initiative in persuading HP and Foxconn to relocate their laptop assembly operations and support operations – the lure being cheaper labor and land, lower taxes and strengthened logistics “HP, Foxconn 2009”.

¹³⁴ However, most of the more than 600 R&D centers established by MNCs are in the coastal cities, chiefly Shanghai and Beijing.

¹³⁵ The general equilibrium implication of such decisions remains murky.

The end result could be a suboptimal dispersion of scientific talent and of research and production facilities. Instead of a few world class centers with a substantial innovation capabilities and a focus on one or a few technologies, there is the risk that the inland cities would fail to acquire the critical mass of expertise in any area and to build innovative clusters. The competition among cities can lead to a massive expenditure on R&D infrastructure and on production capacity most of it redundant as each city attempts to raise local value added and reel in more of the innovation value chain. This may have worked when Chinese cities were beginning to produce manufactures for an expanding global market and investing in production capacity was a safe bet. Developing innovative capacity in a number of intelligent cities requires a different approach and capacity building is only one part of the strategy. An objective of the national innovation policy should be to maximize the productivity of the national innovation system.

The innovativeness of cities is most directly related to the quality of human talent. China's coastal cities have been quicker of the mark because they have been more successful in achieving quality, retaining the most talented knowledge workers and also attracting the cream of the knowledge workers from other parts of the country. The coastal cities are also more open to and accessible to outsiders and have integrated with global knowledge networks. For smaller inland cities to become innovative cities, they would need to specialize and pull in some of the best brains in their fields of specialization from across the country. International research suggests that the presence of "star scientists" can initiate virtuous spirals in the fields where innovation is keyed to scientific advances. The most creative knowledge workers are among the most mobile and able to choose from among competing locations based on a number of preference criteria, among which the livability of cities is often the highest ranked. Others are connectedness, and the reputation of local universities. The biotech cluster in San Diego arose because a number of star scientists (just 4) were enticed by the amenities offered by the city and because the university offered singular opportunities.

Wuhan for example, has the topography and the potential to morph into a city as attractive for the Chinese (and eventually, international) creative class as Austin or San

Diego or Singapore but the potential of its many watercourses has yet to be exploited and little effort is going into a redesigning of the city in order to reverse its drabness and sprawl. Any serious attempt to become an innovative city built on the quality of talent which after all is the life blood of innovation, will have to combine urban design and renewal with a focus on developing a few core areas of world class expertise.

It may be misleading to think that the only industries appropriate for innovative cities are the so-called hi-tech ones with the largest number of patents in recent years. These deservedly attract the most attention and resources, however, many traditional industries can generate handsome returns through innovations that leverage findings in the life sciences and ICT¹³⁶. The dairy industries in Denmark and in New Zealand, two of the leading exporters, have enhanced competitiveness and profitability with the help of innovations that improve herd management, optimizing the feed of animals and monitoring the condition of individual head of cattle. Efforts to reduce water consumption by the meat packing and beverage industries and to control pollution, is prompting a host of innovations that contribute to the bottom line of firms. The textile industry is improving the variety of its offerings and the attributes of materials as a result of advances in nanotechnology. The huge construction materials industry is primed for technological change as the efforts to minimize GHGs gathers momentum. Likewise manufacturers of machinery and equipment, at the heart of the industrial economy, are also faced with the challenge of designing machines and techniques so as to utilize different kinds of material, reduce waste, and lessen energy consumption. The point is that successful intelligent cities do not all have to join the rush towards the electronics, biotech¹³⁷ and transport and renewable energy sectors. There is plenty of other low hanging fruit around and numerous innovations to be made in seemingly mundane industries some of which will require an adroit combination of technologies – the food processing industry being one such. This industry, which is a natural for cities in Northeast China, such as Changchun, is ripe for innovations to sharply cut back on waste,

¹³⁶ The bio-pharmaceutical sector worldwide is struggling with diminishing returns to R&D and looks less attractive than it did a decade ago. See EIU (2011).

¹³⁷ The bio-pharmaceutical sector worldwide is struggling with diminishing returns to R&D and looks less attractive than it did a decade ago. See EIU (2011).

pollution, energy and water use and to introduce foods that are more nutritious and safeguard health.

China's inland cities host many medium and low tech industries and these could expand as coastal cities scale back activities in these areas. The point to consider is whether the future focus of innovative activities could be on some of these industries rather than the fashionable hi-tech ones. The comparative innovation advantage of a Changchun might lie in food processing and not in the auto industry. And food processing may call for the development of research in the life sciences in a few specific areas and in areas such as packaging. In other words, a realistic assessment of innovation potential must start from a clear understanding of existing competitive advantage and promising future niches for which the competition from other will not be too fierce. In electronics and auto parts, it will be deadly and inland cities might well consider whether they want to invest scarce human resources and capital in becoming at best the second ranked innovative cities in a high tech industry as against the leading innovative city in a medium tech or even a formerly low tech industry which they are able to revolutionize through innovation. Such innovation is more likely to be inclusive than innovation in advanced materials for example.

Although human talent is the main contributor to the innovation in cities, the firms that conduct most of the downstream research have a large role to play.

Concluding Observations

Technological progress and the flourishing of innovation in China will be the function of a competitive, globally networked ecosystem constructed in two stages during 2011- 2030. Government technology cum competition policies¹³⁸ will provide most of the impetus in the first stage but success will hinge on the quality of the workforce, the initiative and policies of firms, the emergence of supporting services and the enabling

¹³⁸ Recently, Aghion, Boulanger and Cohen (2011) have urged a reconsideration of industrial policies subject to transparent governance criteria that help boost competitive industries pushing technology frontiers.

environment provided by cities. Human talent is the source of innovation: its flowering depends on the research infrastructure in firms and cities and the degree of global networking. The innovativeness of the business sector is a function of many factors some of which such as management, competition and strategy, are listed above.

With respect to China's emerging innovative cities (coastal and inland), two points need to be emphasized. First, state owned and state controlled enterprises continue to account for a significant share of production in key industries. Second although the innovation systems created by the cities are encouraging new entrants, it is not apparent from the low rate of entry and exit that truly innovative firms, especially privately owned SMEs are being groomed or that struggling firms are allowed to fail in sufficient numbers. SOEs tend to be among the less innovative firms and low on the scale of productivity. The larger their share of industrial output and of R&D spending, the more protective municipal governments are of local industry, the less easy it will be for cities to enhance innovation capabilities. The best bet is an innovation system anchored to and drawing its energy from a competitive national economy.

Annex A
Annex Tables

Table 1: Annual TFP growth rate: major industries, 1999-2004

	China	Japan	Korea
Construction	-1.74	0.18	-1.06
Food and Kindred Products	-0.29	1.20	1.91
Textile Mill Products	0.16	1.56	1.65
Apparel	0.80	1.00	2.65
Paper and Allied Products	1.47	0.57	1.57
Chemicals	0.60	1.94	-0.97
Stone, Clay and Glass Products	3.70	2.09	3.48
Primary Metals	-0.28	1.53	-2.85
Non-electrical Machinery	2.71	1.78	1.65
Electrical Machinery	2.83	5.18	11.05
Motor Vehicles	2.78	1.13	1.39
Transportation	4.94	1.80	9.15

Source: Keiko Ito, Moosup Jung, Young Gak Kim, Tangjun Yuan, 2008, "A comparative Analysis of Productivity Growth and Productivity Dispersion: Microeconomic Evidence Based on Listed Firms from Japan, Korea and China", Working Paper Series, CCAS No.008

Table 2: Top USPTO patents by inventor with Chinese residents, 2005-2009

Class	Rank	Class Title	% of Total Patents
439	1	Electrical Connectors	10.3%
361	2	Electricity: Electrical Systems and Devices	6.8%
370	3	Multiplex Communications	3.4%
382	4	Image Analysis	3.2%
		Drug, Bio-Affecting and Body Treating	
424	5	Compositions (includes Class 514)	2.8%
		DP: Database and File Management or Data	
707	6	Structures (Data Processing)	2.5%
455	7	Telecommunications	2.1%
		Semiconductor Device Manufacturing:	
438	8	Process	1.9%
375	10	Pulse or Digital Communications	1.7%
		Organic Compounds (includes Classes 532-	
532	14	570)	1.4%
435	17	Chemistry: Molecular Biology and	1.1%

	Microbiology	
385	Optical Waveguides	0.8%
356	Optics: Measuring and Testing	0.6%
280	Land Vehicles	0.5%
99	Foods and Beverages: Apparatus	0.2%
123	Internal-Combustion Engines	0.2%
180	Motor Vehicles	0.1%

Source: USPTO

Table 3: WIPO Patent Cooperation Treaty, Share of International Patents by Sector, 2007-2009

Sector of Technology / Field of Technology		Worldwide Ratio	China Ratio	% by China
	Total *	100.00%	100.00%	3.15%
I	Electrical engineering	29.48%	53.14%	5.67%
1	Electrical machinery, apparatus, energy	5.20%	5.38%	3.25%
2	Audio-visual technology	3.16%	2.46%	2.45%
3	Telecommunications	4.61%	11.33%	7.73%
4	Digital communication	4.69%	25.76%	17.28%
5	Basic communication processes	0.87%	0.78%	2.84%
6	Computer technology	6.37%	5.11%	2.53%
7	IT methods for management	1.27%	0.70%	1.72%
8	Semiconductors	3.31%	1.62%	1.54%
II	Instruments	16.23%	7.86%	1.52%
9	Optics	2.96%	1.59%	1.69%
13	Medical technology	5.90%	2.72%	1.45%
III	Chemistry	29.61%	18.49%	1.97%
15	Biotechnology	3.61%	1.98%	1.73%
16	Pharmaceuticals	37.67%	4.55%	2.34%
18	Food chemistry	1.11%	0.72%	2.04%
19	Basic materials chemistry	3.42%	1.68%	1.54%
20	Materials, metallurgy	2.00%	1.37%	2.16%
21	Surface technology, coating	2.04%	1.08%	1.67%
22	Micro-structural and nano-technology	0.25%	0.04%	0.45%
23	Chemical engineering	2.76%	2.08%	2.38%
24	Environmental technology	1.51%	1.20%	2.49%
IV	Mechanical engineering	18.31%	12.93%	2.22%
32	Transport	3.46%	2.21%	2.01%

*Note: Under the WIPO approach, one application may have several IPC classes and may belong to different technology field. In this case, every technology field will be counted. As a result, the sum of the total number of all technology fields could be larger than the total number of applications in the year.

Source: China State Intellectual Property Office

Table 4: Sector Composition of New Entrants (Legal Unit) by Established Time, Guangdong, Beijing and Zhejiang, 2008

(%)	Guangdong			Beijing			Zhejiang		
	1996	2001	2006	1996	2001	2006	1996	2001	2006
	-	-	-	-	-	-	-	-	-
	2000	2005	2008	2000	2005	2008	2000	2005	2008
Manufacturing	29.0	35.7	32.8	14.6	10.6	6.36	51.2	48.9	42.9
	3	1	4	5	4		2	8	8
Processing of Food from Agricultural Products	0.84	0.58	0.32	0.49	0.26	0.14	1.25	0.75	0.55
Manufacture of Foods	0.86	0.59	0.34	0.53	0.29	0.19	0.50	0.33	0.27
Manufacture of Beverage	0.29	0.24	0.15	0.20	0.11	0.05	0.65	0.46	0.31
Manufacture of Tobacco	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manufacture of Textile	1.24	1.72	1.19	0.33	0.21	0.11	5.30	5.78	4.86
Manufacture of Textile Wearing Apparel, Foot ware and Caps	1.68	2.54	2.80	0.95	0.76	0.69	2.22	2.34	2.30
Manufacture of Leather, Fur, Feather and Its Products	0.86	1.24	1.60	0.09	0.06	0.06	1.78	1.40	1.32
Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, Straw	0.46	0.54	0.61	0.20	0.22	0.24	0.75	0.78	0.82
Manufacture of Furniture	0.97	1.02	1.16	0.46	0.44	0.42	0.55	0.58	0.63
Manufacture of Paper and Paper Products	1.15	1.47	1.26	0.38	0.28	0.21	1.77	1.45	1.20
Printing, Reproduction of Recording Media	1.52	1.67	1.00	0.62	0.41	0.21	1.85	1.56	0.89
Manufacture of Articles for Culture, Education and Sport Activity	0.62	0.67	0.55	0.17	0.11	0.05	1.01	1.04	0.88
Processing of Petroleum ,Coking, Processing of Nucleus Fuel	0.07	0.07	0.04	0.14	0.06	0.02	0.05	0.04	0.04
Manufacture of Chemical Raw Material and Chemical Products	1.58	1.63	1.07	1.07	0.66	0.24	1.86	1.53	1.05
Manufacture of Medicines	0.16	0.17	0.09	0.30	0.18	0.06	0.29	0.21	0.13
Manufacture of Chemical Fiber	0.04	0.06	0.02	0.02	0.01	0.01	0.21	0.23	0.14
Manufacture of Rubber	0.33	0.45	0.43	0.10	0.06	0.03	0.69	0.58	0.44
Manufacture of Plastic	2.56	3.21	2.89	0.75	0.48	0.25	3.72	3.74	3.26
Manufacture of Non-metallic Mineral Products	1.77	1.77	1.31	1.02	0.84	0.43	1.82	1.73	1.41
Manufacture and Processing of Ferrous Metals	0.11	0.19	0.14	0.05	0.06	0.02	0.40	0.41	0.35
Manufacture and Processing of Non-ferrous Metals	0.26	0.40	0.33	0.11	0.09	0.03	0.52	0.50	0.40
Manufacture of Metal Products	3.22	3.87	3.75	1.40	1.13	0.63	3.59	3.39	3.09
Manufacture of General Purpose Machinery	1.15	1.57	1.51	1.28	0.90	0.56	6.46	6.64	6.00
Manufacture of Special Purpose Machinery	1.09	1.64	1.87	1.05	0.80	0.43	2.30	2.41	2.18
Manufacture of Transport Equipment	0.70	0.80	0.56	0.51	0.43	0.20	2.87	2.65	2.73
Manufacture of Electrical Machinery and Equipment	2.34	3.08	3.10	0.87	0.64	0.41	4.43	4.07	3.79
Manufacture of Communication, Computer, Other Electronic Equipment	1.77	2.73	2.96	0.70	0.52	0.25	1.18	1.22	1.11
Manufacture of Measuring Instrument,	0.40	0.46	0.49	0.58	0.43	0.21	1.23	0.87	0.66

Machinery for Cultural and Office Work									
Manufacture of Artwork, Other	0.87	1.14	1.05	0.28	0.20	0.20	1.84	2.09	2.01
Manufacture									
Information Transfer, Computer Services and Software	1.41	2.78	3.52	4.86	6.80	6.69	1.11	2.40	3.15
Telecommunications and Other Information	0.25	0.43	0.55	0.74	1.05	0.92	0.18	0.20	0.21
Transmission Services									
Computer Services	0.45	1.16	1.57	1.78	2.23	2.23	0.56	1.60	1.98
Software	0.70	1.18	1.40	2.34	3.52	3.55	0.37	0.61	0.96
Finance	0.23	0.29	0.37	0.24	0.40	0.47	0.18	0.30	0.59
Banking	0.08	0.01	0.05	0.05	0.01	0.04	0.05	0.03	0.03
Securities	0.04	0.02	0.01	0.05	0.04	0.05	0.01	0.00	0.02
Insurances	0.05	0.18	0.18	0.06	0.21	0.18	0.04	0.09	0.14
Other financial Activities	0.06	0.08	0.13	0.09	0.14	0.20	0.08	0.17	0.40
Tenancy and Business Services	9.04	9.01	9.93	12.7	17.3	20.1	6.45	6.12	8.68
				7	8	3			
Leasing	0.10	0.17	0.20	0.71	0.68	0.72	0.16	0.20	0.38
Business Services	8.95	8.84	9.73	12.0	16.7	19.4	6.30	5.91	8.30
				5	1	1			
Scientific Research, Technical Service and Geologic Perambulation	1.98	2.87	3.16	6.68	7.53	8.69	1.74	2.21	2.63
Scientific Research and Experiment	0.30	0.63	0.92	0.63	0.79	0.75	0.17	0.18	0.22
Development									
Technical Service	1.35	1.78	1.75	2.67	2.93	2.74	1.05	1.30	1.23
Scientific Exchange and Disseminate	0.32	0.45	0.48	3.32	3.72	5.12	0.50	0.72	1.17
Service									
Geologic Perambulation	0.01	0.01	0.01	0.05	0.08	0.06	0.01	0.01	0.01
Education	3.97	2.42	1.56	1.89	1.85	1.66	3.24	2.04	1.31

Source: Economic Census yearbook, Beijing, Guangdong and Zhejiang 2008

*Note: For example, 29.03% represent the proportion of the aggregate newly entering firms established from year 1996 to year 2000 in Guangdong province were manufacturing firms. New entrants are approximate estimated by the established time of the current survival firms (some firms that have closed down before the survey year were not accounted in calculation). If the firm change the industry affiliation, the data will reflect the establish time of the firm instead of the time that the firm enter the new industry. This may underestimated the new entry of S&T firms in recent year if a large proportion of firms changed their industry affiliation from traditional sectors to high-tech sectors.

Table 5: Number of Patents in Force in High-tech Industry by Industrial Sector and Registration Status, 2009

	Large-sized Enterprises	Share (%)	Middle-sized Enterprises	Share (%)	Small-sized Enterprises	Share (%)
Total	22975	55.81	8855	21.51	9340	22.69
Manufacture of Medicines	1460	24.26	2451	40.73	2106	35.00

Manufacture of Chemical Medicine	795	32.41	967	39.42	691	28.17
Manufacture of Finished Traditional Chinese Herbal Medicine	646	29.16	1031	46.55	538	24.29
Manufacture of Biological and Biochemical Chemical Products	10	1.32	284	37.47	464	61.21
Manufacture of Aircrafts and Spacecrafts	368	59.16	197	31.67	57	9.16
Manufacture and Repairing of Airplanes	367	69.11	113	21.28	51	9.60
Manufacture of Spacecrafts	1	1.52	59	89.39	6	9.09
Manufacture of Electronic Equipment and Communication Equipment	17120	69.70	4178	17.01	3264	13.29
Manufacture of Communication Equipment	14000	89.68	770	4.93	841	5.39
Manufacture of Radar and Its Fittings	12	24.49	31	63.27	6	12.24
Manufacture of Broadcasting and TV Equipment	83	27.04	66	21.50	158	51.47
Manufacture of Electronic Appliances	2084	43.98	1523	32.14	1131	23.87
Manufacture of Electronic Components	328	18.50	848	47.83	597	33.67
Manufacture of Domestic TV Set and Radio Receiver	553	41.02	612	45.40	183	13.58
Manufacture of Other Electronic Equipment	60	8.15	328	44.57	348	47.28
Manufacture of Computers and Office Equipments	3525	70.28	667	13.30	824	16.43
Manufacture of Entire Computer	2630	94.47	108	3.88	46	1.65
Manufacture of Computer Peripheral Equipment	437	27.96	444	28.41	682	43.63
Manufacture of Office Equipment	1	1.25	41	51.25	38	47.50
Manufacture of Medical Equipments and Measuring Instrument	502	10.14	1362	27.50	3089	62.37
Manufacture of Medical Equipment and Appliances	112	7.85	322	22.58	992	69.57
Manufacture of Measuring Instrument	390	11.06	1040	29.49	2097	59.46

Source: China Statistics Yearbook on High Technology Industry 2010

Table 6: Innovation Inputs and Outputs of on Industrial Enterprises in China, by enterprise size, 2009 (%)

	Percentage of Enterprises Having R&D Activities	R&D expenditure as percentage of sales revenue of core businesses	R&D Personnel as a percentage of total employment	Patent in force per 100 million Yuan of R&D expenditure	Patents in force per 100 R&D Personnel
Total	8.47	0.74	2.19	29.18	6.18
Large and Medium-sized Enterprises	30.48	1.03	3.19	23.58	5.37
Small-sized Enterprises	6.16	0.28	0.99	61.90	9.27

Source: China Statistical Yearbook on Science and Technology 2010

Table 7: Innovation Inputs and Outputs of on Industrial Enterprises in High-tech Industry in China, by enterprise size, 2009 (%)

	Percentage of Enterprises Having R&D Institutions	Percentage of Enterprises Having R&D Activities	R&D expenditure as percentage of sales revenue of core businesses	R&D Personnel as a percentage of total employment	Patent in force per 100 million Yuan of R&D expenditure	Patents in force per 100 R&D Personnel
Total	17.52	25.53	1.63	4.96	42.51	8.67
Large -sized Enterprises	53.61	61.68	1.71	6.06	43.67	10.81
Medium-sized Enterprises	40.82	46.81	1.81	4.87	28.01	5.22
Small-sized Enterprises	12.01	20.42	1.12	3.58	74.03	10.11

Source: China Statistical Yearbook on Science and Technology 2010

Table 8: Foreign Direct Investment: Capital Utilized: by Industry, 2004-2009

	2004	2007	2009
Total	100	100	100
Agricultural	1.84	1.11	1.52
Agricultural: Farming	0.89	0.47	0.80
Mining	0.89	0.59	0.53
Manufacturing	70.95	48.93	49.72
Textile	3.88	2.21	1.48
Chemical Material & Product	4.38	3.46	4.24
Medical & Pharmaceutical Product	1.11	0.72	1.00
Universal Machinery	3.58	2.58	3.17
Special Purpose Equipment	3.13	2.77	2.74
Comm, Computer & Other Electronic Equip	11.64	9.20	7.63
Electricity, Gas & Water Production & Supply	1.87	1.28	2.25
Construction	1.27	0.52	0.74
Transport, Storage & Postal Service	2.10	2.40	2.69
Information Transmission, Computer Service& Software	1.51	1.78	2.39
Wholesale and Retail Trade	1.22	3.20	5.73
Accommodation & Catering Trade	1.39	1.25	0.90
Banking & Insurance	0.42	10.79	4.77
Real Estate	9.81	20.46	17.86
Leasing and Commercial Service	4.66	4.81	6.46
Scientific Research, Polytechnic Service & Geological	0.48	1.10	1.78
Water Conservancy, Environment & Public Utility Mgt	0.38	0.33	0.59
Residential and Other Service	0.26	0.87	1.69
Education	0.06	0.04	0.01
Health Care, Social Security & Welfare	0.14	0.01	0.05
Culture, Sport & Recreation	0.74	0.54	0.34
Public Management and Social Organization	0.00	0.00	0.00

Source: CEIC database

Table 9: Patent family applications by value and country absolute volume

	High Value			Intermediate Value			Low Value		
Year	CN	DE	US	CN	DE	US	CN	DE	US
1990	5	2,139	5,784	51	10,101	40,232	27,343	32,021	40,232
1991	5	1,781	4,747	37	10,445	39,887	33,158	35,216	39,887
1992	7	1,727	4,696	59	10,614	42,843	43,215	38,082	42,843
1993	4	1,868	4,314	47	11,014	48,298	44,879	40,573	48,298
1994	5	2,056	4,200	69	11,766	55,841	42,237	42,400	55,841
1995	3	2,107	3,888	64	12,073	62,261	41,296	43,300	62,261
1996	4	2,100	3,980	74	14,003	61,888	46,287	47,106	61,888
1997	8	1,851	3,977	97	15,218	68,525	48,099	49,319	68,525
1998	6	1,836	3,799	121	16,349	65,965	50,476	51,057	65,965
1999	5	1,543	3,743	160	17,167	66,363	59,659	52,417	66,363
2000	2	1,421	3,312	269	16,807	65,797	74,843	51,879	65,797
2001	10	980	2,564	333	16,143	62,624	87,826	49,961	62,624
2002	15	644	2,361	461	14,896	59,977	109,524	46,721	59,977
2003	13	556	2,027	759	15,603	50,830	133,444	47,140	50,830
2004	27	629	2,142	1,347	17,345	49,273	147,734	50,054	49,273
2005	25	606	1,722	2,528	18,321	50,098	187,067	47,245	50,098
Sum	141	23,843	57,254	6,476	227,867	890,706	1,177,087	724,491	890,706

Source: Philipp Boeing and Philipp Sandner (2011)

Table 10: Regional and Provincial Productivity in China (RMB10K/person)

		2004	2005	2007	2009
Eastern region	Region	3.625	4.137	5.359	6.518
	Beijing	6.771	7.482	8.416	9.683
	Fujian	3.171	3.516	4.627	5.642
	Guangdong	4.371	4.757	5.873	
	Guangxi	1.296	1.508	2.158	6.996
	Hainan	2.180	2.368	2.949	2.711
	Hebei	2.481	2.912	3.843	3.834
	Jiangsu	4.034	4.721	6.139	4.420
	Liaoning	3.419	4.048	5.322	7.596
	Shandong	3.041	3.623	4.934	6.946
	Shanghai	9.938	10.696	13.905	6.220
	Tianjin	7.373	8.662	11.671	16.192
	Zhejiang	3.767	4.196	5.195	14.828
Central Region	Region	1.890	2.201	3.004	3.937
	Anhui	1.378	1.543	2.047	2.727
	Heilongjiang	2.926	3.390	4.256	5.089

	Henan	1.531	1.870	2.601	3.275
	Hubei	2.176	2.436	3.341	4.285
	Hunan	1.567	1.780	2.454	3.342
	Inner Mongolia	2.984	3.742	5.632	8.526
	Jiangxi	1.695	1.925	2.505	3.411
	Jilin	2.799	3.293	4.821	6.144
	Shanxi	2.422	2.831	3.699	4.600
Western Region	<i>Region</i>	<i>1.436</i>	<i>1.625</i>	<i>2.199</i>	<i>2.939</i>
	Chongqing	1.594	1.784	2.304	3.476
	Gansu	1.277	1.435	1.966	2.408
	Guizhou	0.774	0.893	1.201	1.671
	Ningxia	1.802	2.023	2.873	4.120
	Qinghai	1.772	2.030	2.836	3.787
	Shaanxi	1.685	1.952	2.844	4.256
	Sichuan	1.417	1.604	2.198	2.862
	Tibet	1.634	1.789	2.227	2.610
	Xinjiang	2.967	3.407	4.399	5.158
	Yunnan	1.283	1.411	1.823	2.260

Note: 1) Productivity is calculated by dividing regional GDP with region's labor force.
Source: China Statistical Yearbook 2005-2010

Table 11: Domestic Patents Granted in Different Provinces in China, 2009

East Region		Middle Region		West Region	
Beijing	22921	Anhui	8594	Chongqing	7501
Fujian	11282	Heilongjiang	5079	Gansu	1274
Guangdong	83621	Henan	11425	Guizhou	2084
Guangxi	2702	Hubei	11357	Ningxia	910
Hainan	630	Hunan	8309	Qinghai	368
Hebei	6839	Inner	1494	Shaanxi	6087
Jiangsu	87286	Mongolia	2915	Sichuan	20132
Liaoning	12198	Jiangxi	3275	Tibet	292
Shandong	34513	Jilin	3227	Xinjiang	1866
Shanghai	34913	Shanxi		Yunnan	2923
Tianjin	7404				
Zhejiang	79945				

Source: China Statistical Yearbook on Science and Technology 2010

Table 12: Innovation Inputs and Outputs of on Industrial Enterprises in China, 2009 (%)

	Percentage of Enterprises Having R&D	Percentage of Enterprises Having R&D	R&D expenditure as percentage of sales	R&D Personnel as a percentage of total	Patent in force per 100 million Yuan of R&D	Patents in force per 100 R&D Personnel
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	Institutions	Activities	revenue of core businesses	employment	expenditure	
Total	5.91	8.47	0.74	2.19	29.18	6.18
State-owned Enterprises	10.61	14.12	0.69	2.63	17.92	3.71
# Large SOEs	56.56	50.86	0.85	3.48	14.10	3.27
Private Enterprises	6.38	4.07	0.39	1.22	43.42	7.44
Enterprises with Funds from Hong Kong, Macau and Taiwan	10.41	7.71	0.76	1.76	28.81	5.62
Foreign Funded Enterprises	8.22	11.62	0.69	2.18	26.17	6.32

Source: China Statistical Yearbook on Science and Technology 2010

Table 13: Distribution of Innovation Inputs in China, by type of performer, 2009 (%)

	Number of Enterprises (unit)	Share	R&D Personnel (thousand)	Share	Expenditur e on R&D (bn)	Share	Number of Patents in Force (piece)	Share
Total	429378	100.0	1914.27	100.0	405.20	100.0	118245	100.0
State-owned Enterprises	8860	2.06	174.77	9.13	36.16	8.92	6478	5.48
# Large-size SOEs	419	0.10	119.64	6.25	27.75	6.85	3913	3.31
Private Enterprises	253366	59.01	356.35	18.62	61.09	15.08	26528	22.43
Enterprises with Funds from Hong Kong, Macau and Taiwan	33865	7.89	198.82	10.39	38.80	9.58	11179	9.45
Foreign Funded Enterprises	40502	9.43	284.39	14.86	68.65	16.94	17965	15.19

Source: China Statistical Yearbook on Science and Technology 2010

Table 14: Distribution of Innovation Inputs and Outputs in *High-tech Industry* in China, by type of performer, 2009 (%)

	Number of Enterpris es (unit)	Share	R&D Personn el (thousa nd)	Share	Expenditure on R&D (bn)	Share	Numb er of Patent s In Force (piece)	Share
Total	27218	100.0	474.63	100.0	96.84	100.0	41170	100.0
Domestic	17922	65.85	297.83	62.75	60.69	62.67	29254	71.06
#State-owned Enterprises	469	1.72	26.32	5.54	5.37	5.54	1178	2.86
Enterprises with Funds from Hong Kong, Macau and Taiwan	3809	13.99	70.39	14.83	13.37	13.81	4713	11.45
Foreign Funded Enterprises	5487	20.16	106.41	22.42	22.79	23.53	7203	17.50

Source: China Statistics Yearbook on High Technology Industry 2010

Table 15: Innovation Inputs and Outputs of on Industrial Enterprises in *High-tech Industry* in China, 2009 (%)

	Percentage of Enterprises Having R&D Institutions	Percentage of Enterprises Having R&D Activities	R&D expenditure as percentage of sales revenue of core businesses	R&D Personnel as a percentage of total employment	Patent in force per 100 million Yuan of R&D expenditure	Patents in force per 100 R&D Personnel
Total	17.52	25.53	1.63	4.96	42.51	8.67
Domestic	18.32	27.11	2.97	7.32	48.21	9.82
#State-owned Enterprises	27.93	41.36	3.81	8.70	21.95	4.48
Enterprises with Funds from Hong Kong, Macau and Taiwan	16.30	22.92	1.13	3.29	35.25	6.70
Foreign Funded Enterprises	15.73	22.18	0.83	3.16	31.61	6.77

Source: China Statistics Yearbook on High Technology Industry 2010

Table 16: The role of various entities involved in innovation strategy

Entities	Objectives	Incentive /constraint mechanisms	The actions that the entities should and could adopts	The policies and regimes that could influence the behaviors of the entities
Enterprises	Sustainable earning capacity; Long-term competitiveness	Market competition as driving force for innovation (Schumpeter innovation)	Improve management; Purchase of technology; R&D investment; Recruit talents	Promote sufficient competition and market regimes; Protection of IPR; Enhance the supply of human resources; Encourage innovative entrepreneur; Provide tax exemption for enterprise R& D behavior; Demands-side induction
Foreign funded enterprises	Sustainable earning capacity; Long-term competitiveness	Market competition as driving force for innovation (Schumpeter innovation)	Purchase technology from the parent company; Launch local R&D activities	Promote a fully complete environment; IPR protection system; Enhance the supply of human resources; Provide tax exemption for enterprise R& D behavior;

				Promote the establishment of R&D institutions
Universities	Cultivate talents; Frontier research	Teaching evaluation; Funds granted from the state; Peer pressure	Reform the orientation of education system and teaching methods; Encourage and permit autonomy in research	Grant more independence to the management of university; Reform the evaluation and appraisal system of university; Reform the initiation and evaluation system of major R&D project
R&D institutions	Applied and basic research; Cultivate talents	Funds granted from the state; Peer pressure	Create preferable internal incentive mechanisms	Reform and rationale the financial aid methods for major R&D projects; Increase the proportion of labor (hiring experts) budget
Engineers and scientists	Wealth creation; Pursue the true	Professional discipline; Peer pressure	Continually studying; Autonomy in research	Reform and rationale the financial aid methods for major R&D projects; Permit autonomy in research; Reform the appraisal and compensation mechanisms for R&D researchers (performance related pay versus seniority pay)
Industry associations	Serve the firms	Trust of the firms; Well recognized by the social society	Promote the cooperation between firms; Improve communication between the government and industry; Create R&D alliances	Grant more autonomy to the industry associations
Financial institutions	Long-run economic return	High economic return; Comply with the laws and regulations	Professional investment team; Good risk management mechanisms	Create good financial eco-system; Keep balance between competition and supervision; Provide tax deduction for the capital invested into the high-tech enterprises

Central government	Economic and social development; National security	Demand from the public at large; Global competitive pressure	Improve the infrastructure, especially those related to ICT, to facilitate the transmission and flow of knowledge; Strengthen the social security system and build up of market; Increase investment in education and enhance the quality of education; Improve national innovation system; Sustainable investment in basic research; Promote R&D by firms; Organize major R&D projects; Create initial demands through the first-buyer strategy of government procurement	Reform of the administrative management system; Create a law-governed Government; Reflect the demand and interest of the public
Local government	Regional sustainable economic and social development	Performance appraisal by superior; Competition between regions	Improve the infrastructure and system to create a better innovative environment; Promote R&D by firms; Promote the development of local industrial clusters	Change the evaluation mechanisms for the local government; Promote regional competition in precondition of creating a integrated market; Reflect the demand and interest of the public

Annex B

Technology Capability and Innovation Criteria

Cities: Profile and Technological Capacity

- Population of city
- Population growth
- GDP/Capita
- Overall GDP growth rate since 2000; and growth by sectors (in comparison with main competitors in China)
- Number of high-tech companies
- Percent of workers in high-tech fields
- Percent of workforce with advanced degrees
- Number and skill composition of in-migrants (since 2000); where do they go?
- Number and skill composition of out migrants
- FDI

S&T Input-Output Indicators

- Number of firms filing research joint ventures (RJVs)
- Number of research institutes
- Number of full time R&D personnel
- Total public funds invested in R&D (and distribution of spending)
- R&D funds per capita of R&D personnel
- Patents registered by residents at their national offices
- Receipts of royalty and license fees
- Number of scientists & engineers in workforce
- Number of scientific publications (in major journals, past five years)

University Sector

- Number of tertiary institutions and enrollment/graduates; and percentage in science and engineering disciplines
- Percentage of high achieving graduates who stay in municipality (top 5 percent of class). Those who leave, where do they go?
- Enrollment in doctoral programs
- Enrollment in post doctoral programs
- Spending on research as a fraction of university budgets; as a fraction of total spending on R&D in municipality
- Number of spin-offs
- Number of contracts with enterprises; kinds of contracts?
- Number of patent applications; number granted
- Strongest university departments (by what criteria? National ranking)
- Leading research institutes (criteria? national ranking)

Manufacturing Sector

- Largest three manufacturing sectors (percent of GVIO)
- Fastest growing three manufacturing sectors (and share of GVIO)
- Top five exports to rest of China and rest of world in 2000 and latest year; top five fastest growing exports
- Largest five firms by turnover

- Top 3 firms in the three fastest growing manufacturing subsectors (how does the largest firm in this set compare in size with the leading Chinese firm in this subsector)
- Number of new entrants in these three subsectors in the past 5 years
- Number of exits from these subsectors in the past 5 years
- Number of high impact firms in these subsectors i.e. firms that doubled their output value in 5 years
- R&D spending by subsectors as a percentage of turnover
- Expenditure on technology licensing past 5 years
- Number of patents applied for; number granted
- FDI in these subsectors over past 5 years; Investment from the rest of China in these subsectors; national firms with subsidiaries in city
- Labor force composition of fastest growing subsectors. Increase in employment in 3 fastest growing subsectors
- Number of industrial and technology parks and incubators. Numbers of firms in parks, change in number since 2005

Firms in Selected Subsectors (Based on Firm Surveys)

- Proportion of enterprises that conduct R&D activities to the total number of enterprises
- Proportion of R&D expense to the total sales income
- Proportion of R&D personnel to the total of staff
- Proportion of enterprises that apply for patents
- Proportion of enterprises possessing patents
- Proportion of enterprises creating new products in the past three years
- Percentage of sales derived from new products
- Proportion of enterprises making any technique improvement in the past three years
- Proportion of enterprises having cooperation with high-level education and research institutes
- Proportion of product-export oriented enterprises
- Enterprises whose proportion of sale of new products or products using new techniques is over 25% of total sale
- Proportion of employees with tertiary/ graduate level qualifications
- Proportion of staff with the experience of being trained abroad
- Firm size
- Plant vintage
- Foreign ownership and/or part of multinational group
- Existence of formal R&D department

Policies and Incentives

- Principal industrial policy objectives
- Key policy incentives for achieving these employed since 2000-01
- Results of policy incentives; which ones most effective
- Main problem areas and policy challenges

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