Supporting Report 2

China's Growth through Technological Convergence and Innovation

Executive 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 entered the ranks of middle income countries. With the launch of the 12th FYP, China has re-affirmed its goal of becoming a moderately prosperous society by 2020. This report maintains that China can become 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, while high levels of investment will remain an important source of growth in China through deepening and embodied technological change. By 2030, China expects to have pulled abreast technologically of the most advanced countries and increasingly, its growth will be paced by innovation which pushes outwards the technology frontier in areas of acquired comparative advantage. Both technology catching-up through technological absorption and innovation at the technological frontiers will rest on the success of a number of policies focused on: effective competition, the composition of the business sector and its strategic orientation; agile policymaking and robust regulation which minimizes the risk of crises e.g. from asset bubbles that can depress innovative activity, and which positions the economy to seize evolving opportunities; skill development; R&D; national and international networking to promote innovation; and the nurturing of innovation especially in the areas of green technologies, health and medical services, urbanization modes, and 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-enhancing reforms increased entry of foreign and private firms and stimulated competition in most manufacturing sub-sectors. Even in some "strategic" or "pillar" industries (for example, airlines and telecommunications), the breaking up and corporatization or exit of incumbent mainly state owned providers in the 1990s,strengthened 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 further institutional reforms and measures to enhance the supply of risk capital, will be critical to the making of an innovative economy, as it will induce the deepening of the private sector, reduce barriers to firm entry and exit, promote the growth of dynamic SMEs, prod 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 and 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, university-level education is improving—China now has 11 universities in the top-ranked 200 universities of the world.[1] Even so, the quality of tertiary education more broadly is a matter of concern and some employers are experiencing a serious shortage of the skills required to upgrade processes and the product mix. For China to become an innovative knowledge economy, increased investment in human capital will be critical to the building of analytic and complex reasoning capabilities, enhancing

[1] As ranked by the Times Higher Education Supplement 2011. The list includes universities in Hong Kong (China). http://www.topuniversities.com/world-university-rankings/qs-world-university-rankings-2011

scientific literacy and the knowledge base of students, encouraging creativity and instilling communication and teamwork skills. Raising the volume and quality of skills demands innovation in pedagogical techniques with 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.

China's spending on R&D is on a steep upward trend. This will increase 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. Agricultural research will also continue to contribute substantially to productivity gains, price stability and to food security.

An adequate volume of much needed basic research, by virtue of its public good characteristics, will depend upon government initiatives and funding. Government agencies, key universities and research institutions and some large corporations, 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 Departments of Defense, Energy and Agriculture 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 evaluation and refereeing of research programs and findings with the feedback incorporated in policies. 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 countrywide 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 firms that are "global challengers". The domestic research networks should be incorporated into global research networks so that Chinese companies can also participate in research conducted in other parts of the world. Such participation and with it the creation of global research networks, will be promoted by measures that improve internal organizational and technological capacities and by policies that minimize protectionist tendencies in other countries.

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 potentially significant long run spillover effects, the reputational gains for Chinese cities a few of 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 learns from 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 technologically dynamic fields such as biotechnology, nanotechnology, software and multimedia, will expedite the growth of China's innovation capabilities.

Smart cities will be the locus of technological innovation andof nascent green growth 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 generating, debating, 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 provide a business environment conducive to the multiplication of SMEs; 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 knowledge environment, physical and cultural amenities, public services and quality of 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 premier institutions with a measure of autonomy from government but also to ensure that they are disciplined by competition and indicators of performance 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.

With a yearly influx of over 10 million people to the cities, China needs to optimize the planning of urban development, build energy efficient mass public transportation systems and provide affordable housing and inculcate more sustainable urban life styles. Smart and green urbanization will stimulate both research on and the commercialization of green technologies. Energy pricing reform and the enforcing of national environmental and energy efficiency standards will create 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 supported by sound and responsive policymaking.

China may need to develop a culture that encourages more people to boldly pursue new ideas and to push the frontiers of knowledge across a variety of fields.

Introduction

China is determined to become a global innovative powerhouse[2] by 2020. Policy analysis has shown that productivity gains from structural changes[3] and technological catch-up[4] 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 forms[5]. 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 in the new phase of development. 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.

The report is divided into four parts. Part 1 underlines the increasing significance of total factor productivity growth (TFP) as a source of growth,[6] 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.

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[2] This is the projection in China's Science and Technology Medium-to-Long Term Plan. For more discussion and analysis, see Lu, 2006; Xu, 2006; Zhang, Liu amd Lv, 2008; Lv 2009. 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 the DRC's Study on growth prospects. More than 320 million workers continue to derive their livelihoods from agriculture and this number is bound to shrink as agricultural productivity grows. Thus 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.

[6] Jones and Romer (2009) explain the large differences in per capita GDP among counties 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".

I. Growth Drivers: Betting on TFP

Among the larger East Asian economies only three[8] were able to transition from middle to high income category during the second half of the 20th century. Japan did so in the 1960s,[9] 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 the government's industrial and technology policies but introduced by the private sector. The pocket transistor radio, the Walkman, compact automobiles and lean manufacturing[10] were some of the disruptive innovations[11] introduced by Japanese firms which contributed to productivity gains and export successes.[12] South 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 breakthrough 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, leading manufacturers assisted by clusters of smaller suppliers spearheaded technology absorption and innovation.[13] 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 performance. Korea and Taiwan (China) began strengthening their innovation systems in the 1980s through public and private investment in research infrastructure, systematic borrowing from overseas through licensing and other channels and the acceleration of technological progress[14] during the 1990s and early 2000s enabled them to cross the threshold and become a member of the club of 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

[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 Toyota Motor Company was among the pacesetters borrowing, adapting and perfecting for Japanese conditions, techniques and ideas pioneered in the US.

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

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

[13] The keiretsu in Japan, and the chaebol in Korea.

[14] Among the innovations introduced by Korean companies was the 256 MB DRAM (by Samsung in 1998). The dedicated silicon foundry pioneered by Morris Chang at TSMC in 1987 was a fundamental innovation which transformed the chip manufacturing industry and opened the door to fabless chip designers (Perry 2011). See Mathews and Cho (2000); Breznitz (2007); and Hsueh, Hsu and Perkins (2001, specifically the Annex by Ying-yiTu); and Brown and Linden (2009) on the technological development of Korea and Taiwan (China).

introducing innovative designs and special features customized for specific markets.[15] 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,[16] most likely in the 2020s and beyond when China would be morein 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 that will be the ultimate arbiter of growth enhancing innovativeness.

Accounting for China's Growth

A decomposition of China's growth rate is an appropriate starting point. Research conducted by Bosworth and Collins shows that physical capital and TFP[17] contributed 3.2 percent and 3.8 percent respectively to China's GDP growth between 1978 and 2004.[18] During the period 1993 to 2004, their shares were 4.2 percent and 4.0 percent respectively (Table 1)[19] 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). Agricultural output grew steadily at an average annual rate of 4.5 percent between 1978 and 2009, with TFP gains averaging 2 percent per annum. The performance of agriculture was aided by market incentives, ownership reform, land saving technologies and the diversification of production from grains to higher value items such as meat and vegetables. Chen, Jefferson and Zhang (2011) show that TFP rose even more 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.[20] However, metal and non-metal industries, plastics, rubber, petrochemicals and paper achieved comparable gains. Ito and others (2008) reaffirmed these findings. Growth of TFP was strongest for machinery and motor vehicles during 1999–2004 (ranging from 2.71 percent p.a. to 2.83 percent p.a.). Glass and clay products and paper also registered large gains. (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 percent.[21] Growth of

[15] Breznitz and Murphree (2011) argue that China does not over the near term, 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. As to innovation and China's sustainable development, see Fang, Xin (2007), Scientific & technological innovation and sustainable development of China; also see Gao & Liu (2007)

[16] Translating promising discoveries into profitable innovations can take many years if not decades. The high strength synthetic fiber Kevlar created by DuPont took 17 years to achieve commercial viability and it is not an exception.

[17] 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".

[18] 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).

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

[20] Jorgenson, Ho and Stiroh (2007).

[21] 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.

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

Source: Bosworth and Collins (2007).

With capital spending subject to decreasing returns as is evident from the upward trend in ICORs,[22] 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 tapering.[23] In most OECD countries, TFP growth averaged less than 2.0 percent p.a. between 1995 and 2009,[24] the exceptions being Korea and Ireland each of which notched up rates of

[22] 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. With a ratio of investment to GDP approaching 50 percent in 2011, China is now investing far more than Japan did at the height of its boom and deriving a roughly equivalent amount of growth.

[23] Chen, Jefferson and Zhang (2011).

[24] 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.

2.7 percent and 3.1 percent respectively—although Ireland fell to 1.3 percent and Korea to 2.6 percent during 2005–2009.[25]

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 services,[26] 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 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).[27]

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.[28] 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 vulnerabilities[29] 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).

[25] 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

[26] 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 conducts little of the R&D. He calls for a revolution in services in order to catch–up with the U.S.

[27] See Comin (2004).

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

[29] The Fukushima disaster has further sensitized companies to supply chain vulnerabilities.

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
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*

Since 1985, China has broadened its production base and through massive investment, enlarged production capacity and accelerated learning by doing.[30] 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.

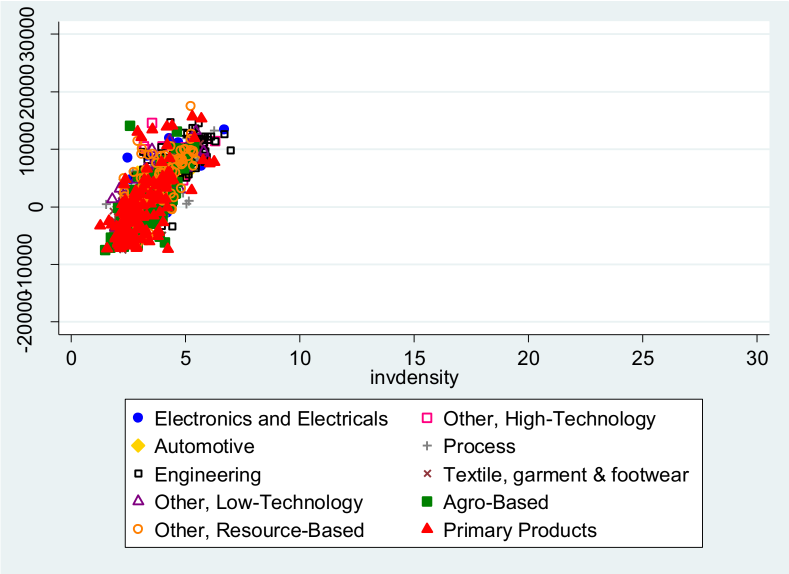
A closer inspection of the products in China's export basket with the highest densities that are upgrades, underscores the fact of China's rapid industrial progress. In 1987, the top 10 commodities with the highest densities, implying that they were more sophisticated than the average, were mainly low-tech 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 competiveness relative to higher income countries. In recent years, the increase in product complexity and the share of products employing advanced technologies is linked to investment by MNCs in upscale manufacturing activities.[31] These findings are similar to those of Felipe et al (2010).[32]

[30] 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.

[31] Koopman and others (2008, 2009).

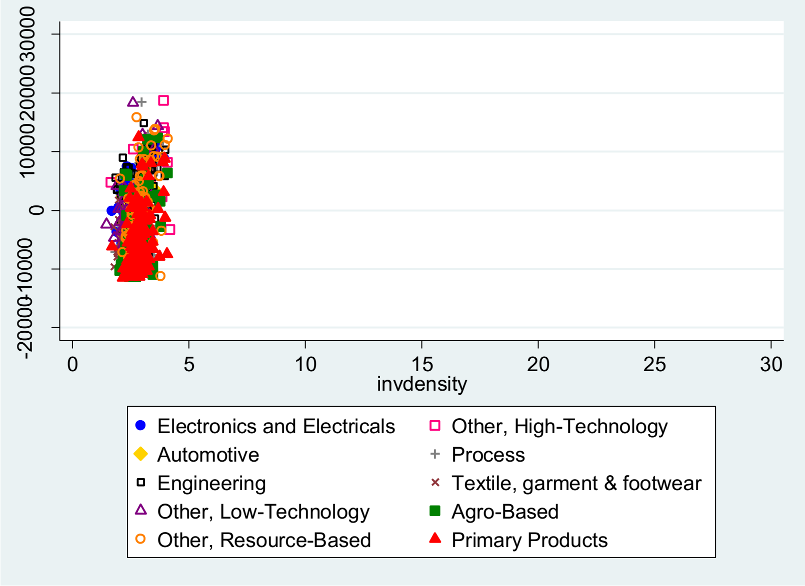
[32] According to Felipe et al (2010) as early as the 1960s, China was exporting 105 commodities (with comparative advantage) from the 779 commodities in their sample, many more than either Korea or Brazil. By 2006, the number had risen to 269, well ahead of Japan (192). Of these, 100 products were from 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 un-weighted PRODY of China's core exports rose from $14,741 in 1962 to $16,307 in 1980 to $17,135 in 2006 (Felipe et al 2010, p.12)

FIGURE 1 Product Space (1987)



Source: Authors' calculations based on UN Comtrade data.

FIGURE 2 Product Space (2006)



Source: Authors' calculations based on UN Comtrade data.
Note: * denotes that data is for the years 1994, 1999 and 2005.

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
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 chemical[33] and

[33] 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).

biological products[34] and products grouped under the mechanical engineering category. The sectoral composition of patents held by Chinese residents favors electronics, electrical engineering and telecommunications 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, telecommunication 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.

Entry of firms by Subsector

China's emerging comparative advantage in manufacturing sub-sectors is supported by data on the entry of new firms. The subsectors with high rates of new entry are metal manufacturing, machinery, and electrical, computing and telecommunications equipment. Meanwhile, 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 are on the average 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 that 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.

[34] 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).

II. Building Technological Capacity

Prior to the industrial revolution in Europe, China led the world in technology.[35] After losing ground for over two hundred and fifty years, China is sparing no effort 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. The next step was to increase the 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 China.[36] 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 thus far have generated few technological spillovers and those too mostly in the vertical plane and in high tech sectors.[37] 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 leakage.[38] In the light of this experience, China is redoubling its own efforts at technological upgrading, indigenous innovation,[39] 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 expand their share of global markets.[40] This approach is exemplified by Lenovo (Tzeng 2011).

Planning Technology Development in China

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

[35] This leadership has been convincingly documented by the series of volumes on China's Science and Technology launched by Joseph Needham and published by Cambridge University Press http://www.nri.org.uk/science.html. See also Subramanian (2011) on why China is well placed to regain its earlier preeminence. Subramanian computes a dominance index based on a country's GDP, its trade and its status as a creditor. He is of the view, that as of 2010, China might already have pulled ahead of the US, and could be well in the forefront by 2030. And this dominance could very likely, extend to the technological domain.

[36] See Walsh (2003). Zhang and Long (2011) provides detailed analysis on MNC's investment in R&D activities in China.

[37] See Moran (2011a&b)

[38] See Moran (2011); Fu and Gong (2011); Tang and Hussler (2011); Bai, Lu and Tao (2010); and Fu, Pietrobelli, and Soete (2011).

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

[40] 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. 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.

indigenous innovation", "a leap-forward in key areas," "sustainable development",[41] 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 others;[42] 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 GDP;[43]
- Increasing rates of patenting to 3.3 per 10,000 people.

An increase in R&D is being complemented by investments in the physical infrastructure supporting technological upgrading.[44] 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 gridand rail transport, are expected to reduce energy consumption.[45] Mobile networks were serving 860 million users by 2010 an increase of 460 million over 2006. In 2010, 450 million users had access to broadband services, more than the total population of the United States[46] (Figure 3).

[41] 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.

[42] 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.

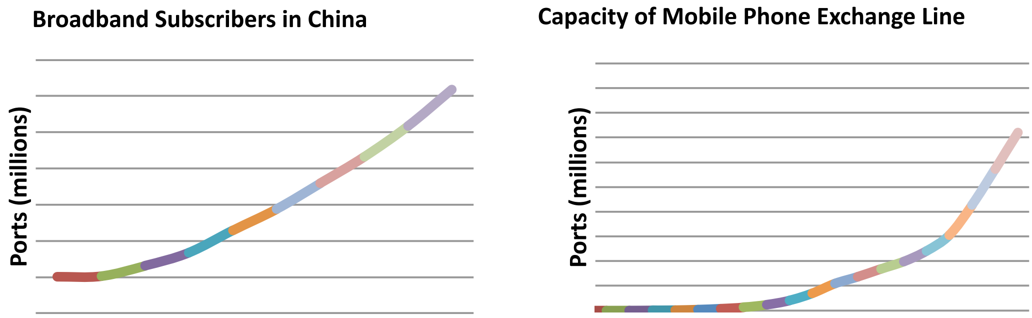
[43] Jian and Jefferson (2007) note that countries appear to experience a "S&T take-off" when their spending on R&D doubles as a share of GDP and begins to approach 2%. China has doubled its spending since the mid 1990s and on current trends will exceed 2% by 2014. "China Bets Big" (2011). According 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).

[44] 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.

[45] 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.

[46] From Ministry of Industry and Information Technology's "2010 Statistical Report on Telecommunications Industry".

FIGURE 3 **China's Communication 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 1700 institutions of higher education are elite Project 211 entities[47] 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 fields.[48]

Between 1996 and 2000, China's global SCI ranking measured by publications increased from 14th to 2nd place.[49] 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 ago.[50] 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.[51]

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 2006.[52] The number of patent applications to the WIPO increased from a little fewer than 23,000 in 1996 to 290,000 in 2008 (Hu 2011, p. 103).[53] A continuing sharp increase through 2009 propelled China to 5th place in

[47] 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.

[48] 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).

[49] See Adams, King and Ma (2009).

[50] "China shoots up rankings as science power, study finds" 2011. See also Gao and Guan ((2009) on the increasing rate of China's S&T output relative to GDP growth.

[51] See ftnt 68 and Hassan (2005); Bai (2005); Preschitschek and Bresser (2010); Italian Trade Commission (2009); and Leydesdorff (2008).

[52] 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.

[53] The National Patent Development Strategy (2011–2020) envisages that patent applications of all kinds will increase from 1.2 million in 2010 to 2 million in 2015 and overseas applications by Chinese residents will double.

WIPO's rankings, but again quantity has not yet been matched by the quality of the patents.[54] Incentives to patent (including incentives offered by provincial authorities)[55] have produced a flood of minor design and utility patents[56] contributing little to advances in knowledge or commercial innovation.[57] Most of the high and mid value patents are being registered by MNCs (See Boeing and Sandner 2011 and Table 9).[58] 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. In 2009, China ranked 11th in the world having filed 667 triadic patents as against 1959 by Korea, 12,715 by the US, and 13,332 by Japan.[59] In 2010, the numbers of patent applications filed by Chinese residents to the United States Patent and Trademark Office (USPTO), the European Patent Office (EPO), and the Japan Patent Office (JPO), stood at 6978, 2049, and 1063 respectively, an increase of 19.6%, 35.7% and 37.7% respective to 2008.[60]

By official count the number of S&T based private firms increased from just 7000 in 1986 to 150,000 in 2006[61] 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[62] 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.[63] Chinese companies are also mastering the latest technologies in areas such as auto assembly and components, PVCs, biopharmaceuticals,[64] nanotechnology,[65] stem

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

55 See Economist (2010, Oct 14th) and Li (2012), which refer to the generous incentives that are offered to researchers and companies and also to bureaucrats in patent offices to approve patents, many of which are of the utility model kind.

[56] Such patents, known as junk patents are not substantively examined or evaluated by the SIPO—the patent being granted with the minimum of scrutiny.

[57] Breznitz and Murphee (2011) observe that most innovation in China thus far is of an incremental sort. Firms in the ICT sector account for the majority of the USPTO and many of the SIPO filings. These firms according to Eberhardt, Hemers and Yu (2011) tend to be young, large, R&D intensive and outward oriented.

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

[59] OECD Factbook 2011, http://dx.doi.org/10.1787/888932505906, 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.

[60] Data supplied by the SIPO.

[61] See Ministry of Science and Technology (2008).

[62] In 2008, Huawei filed more international patents than any other company. It was also the leading filer of patents with SIPO during 1985–2006 with a 34 percent share. See Economist ("Patents Yes" 2010); and Eberhardt, Helmers and Yu (2011).

[63] 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, Zeng Mako and Seward (2009).

[64] 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.

[65] Measured by PPP, China is likely to be spending more on nanotechnology research in 2011 than the US—$2.25 billion vs. $2.18 and several recently established nanotech centers are engaging in cutting edge research. See "China leapfrogs to the forefront of nanotechnology" (2011). On some views regarding the future directions of nanotechnology, see Manoharan (2008).

cell therapeutics,[66] and high density power batteries,[67] high speed trains,[68] telecommunication equipment, wind turbines,[69] single aisle passenger aircraft,[70] booster rockets, space satellites,[71] supercomputers, shipping containers, internet services, electric power turbines, and many other products.[72] Many of the companies introducing innovative products are state owned.

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).[73] Having no big marquee brands or core technologies,[74] China reaps only a small portion of rents from high tech exports, which accrue, mainly to foreign designers and engineers.[75] The most illustrative example is the case of Apple's iPad and iPhone. All iPads and iPhones on sale worldwide are assembled in China by the Taiwanese company Foxconn with homegrown Chinese companies supplying not a single component. In the case of iPhone, the only value captured in China is the wage earned by Chinese assembly workers that accounted for 1.6% of the sales price, with Apple's profits accounting for 58.8%.[76]

This jives with the rankings of China's technological capability presented below.

China versus other East Asian Economies

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 moved faster than most of its neighbors in laying the foundations of a world-class innovation system. However, the efficiency of the emerging innovation system is questionable, the quality will need improving and the urban dimension has been relatively neglected (see next section).

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66 Gwynne (2010).

67 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 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.

68 About one-half all-worldwide investment in high speed rail is occurring in China, and China's $300 billion investment in this industry to date has created state of the art production facilities. See "China's rail exports will survive Wenzhou crash" (2011).

69 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.

70 The first flight of the COMAC C919 is scheduled for 2014, with an in-service target of 2016.

71 By 2011, China had launched over 100 satellites for purposes of surveillance, remote sensing, weather forecasting, telecommunications and most recently, navigation and positioning via the Beidou Navigation Satellite System. (See "Chinese Academy takes space under its wing" 2011; and "Beijing Adds Fuel to Global Space Race 2012). A space station is now in the works. See "China unveils its space station" 2011.

72 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.

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

74 Lenovo and Haier now have the makings of global brands.

75 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.

76 Kraemer, Linden, and Dedrick (2011)

Starting in the 1980s, China began to reform its science and technology system, and initiated four programs—Key Technologies R&D (1982), Spark (1986), High-Technology Research and Development ("863") (1986), and Torch (1988)—aimed at making science and technology serve economic growth and social development, and enhancing S&T capacity to complement its investment in manufacturing capabilities.[77] These and others reforms and programs introduced since, with the focus shifting to innovation after 1990, are now producing results. A number of multidimensional indices measuring capabilities across countries show that China is rapidly augmenting S&T skills, research infrastructure and assimilating information and communications technology (ICT).

According to a ranking of 40 countries produced by the Chinese Academy of Science and Technology for Development (CASTED), China is in 21st place with a point score of 58 as against 100 for the U.S. The index was constructed from five major sub-indices based on 31 indicators. The various subcomponents indicate that China's performance has improved since 2000, in knowledge creation (now in 33rd place—a five point improvement) and innovation performance has risen sharply to 9th place. But as the report observes, efficiency, intensity and quality of research in China still lags behind the frontrunners—the U.S. Switzerland, Japan and Korea—it is seeking to match.

A second ranking of countries by innovativeness comes from the Information Technology and Innovation Foundation.[78] This index covers 40 countries and is based on measures of human capital, investment in R&D and numbers of scientific articles, entrepreneurship, IT, economic policy and economic performance—in other words, this index casts its net broadly. Singapore leads the ITIF list with a score of 73 followed by Sweden with the U.S. in 6th place and China ranked 33rd. The ITIF also prepares a separate ranking of the change in country scores to determine the scale of innovation effort and progress between 1999 and 2009. By this measure, China comes first, followed by Singapore and a number of Northern European countries. Interestingly, the U.S. ranks dead last in this listing because it is the country at the technological frontier in most areas and because of its weak performance on a number of counts.

The European Business School (2010) is the source of a third Innovation Capacity Index (ICI) resting on five pillars:[79] the institutional environment; human capital; training and social inclusion; the regulatory and legal framework; and the adoption and use of ICT. Sweden received the highest score and ranking in 2010–2011 followed by Switzerland and Singapore, Finland and the U.S. The ICI puts China in 64th place even though the report recognizes China's vast potential and huge investment in technology. However, the report observes that China's R&D base is still somewhat weak as are the regulatory and legal frameworks.

The European Innovation Scoreboard (IUS 2011)[80] compares China's performance with reference to several benchmarks against the EU 27. The most recent report concludes that the countries of the EU are ahead of China according to most of the indicators of education and innovation capability. However, China is increasing its lead in the exports of medium and high tech exports and drawing abreast of the EU in tertiary education, international co-publication, business R&D and patenting, while the EU is extending its lead in public R&D expenditure and most cited publications.

INSEAD's Global Innovation Index (GII) provides a fifth measure of China's capabilities. This index ranks 125 countries with reference to measures of innovation input (e.g. institutions, human capital, infrastructure and market and business sophistication) and measures of innovation output, both scientific and creative. China was ranked 29th in 2011, the three top ranked countries being Switzerland, Sweden and Singapore. The GII like the European Innovation

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[77] A full listing of national programs and policy initiatives from 1980 onwards can be found inLv, 2010; Liu and others (2011). An overview of China's S&T system can be found in Swissnex (2011).
[78] http://archive.itif.org/index.php?id=226
[79] http://www.innovationfordevelopmentreport.org/supplement/Supplement_ICI_profiles2010.pdf
[80] http://ec.europa.eu/research/innovation-union/pdf/iu-scoreboard-2010_en.pdf

Scorecard, points to China's improving performance—from 37th place in 2009 to 43rd place in 2010 before ascending to its current position.

A sixth index of "Science and Technology power" computed by Hu Angang, compares China with the four leading nations—the U.S., Japan. Germany and the UK—with reference to five capacities: publications, patents, computer usage, Internet access, and R&D spending. Each of these is given equal weight and Hu (2011, p. 110) finds that China's global share of S&T power rose from 0.82 percent in 1990 to nearly 4 percent in 2000 and to 9.7 percent in 2007 putting it in third place behind the U.S. and Japan.

These six by no means exhaust the indices of innovation capabilities. There are several others compiled by the World Economic Forum, the European Commission, the World Bank, UNCTAD ArCo, UNIDO and still others. All of them arrive at rankings for selected countries by fusing measures of competitiveness, scientific and technological knowledge, ICT and human capital. Information on these rankings and a synthetic index constructed by Archibugi and Coco, are helpfully summarized by Archibugi, Denni, and Filippetti (ADF 2009).[81] According to this consolidated set of rankings, the first place is assigned to Sweden, followed by the U.S. Switzerland, Finland, Japan and Denmark. China is ranked 42nd. It's ranking by the selected indices ranging from 26th in the UNIDO index to 45th in the WEF index with other rankings clustered around 44th place.

Technology development and innovation is a fairly recent focus of China's development strategy,[82] 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 ranks of the top five contenders in most of the indices, will depend upon the efficiency of China's technology policies and the response these policies elicit from the business sector,[83] 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 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 "reform and opening" 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.

[81] http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1526666

[82] The Chinese government formally adapted the "Strategy for Raising the Nation by relying on Science, Technology, and Education (KejiaoXinGuoZhanlue) in 1995", and established the State Leading Group on Science, Technology and Education in 1998, headed by the then premier Zhu Rongji.

[83] See ftnt 35 on the initiatives by Chinese firms. One can add Huawei and ZTE to the list of indigenous innovators.

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 Zhejiang[84] 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 local governments.[85] 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 software.[86] 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 manufacturing capabilities, growing stocks of human capital and strong tertiary institutions. A two-pronged approach that stimulates innovation in coastal urban areas and cultivates more specialized expertise in the leading inland urban centers would increase the likelihood of achieving growth objectives and also serve to reduce income and productivity gaps.[87] 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.

[84] See Huang, Zhang and Zhu (2008) on the footwear cluster of Wenzhou. Other clusters producing cigarette lighters and eyeglass frames have also flourished but as wages have risen, foreign demand weakened and credit tightened in 2011, the Wenzhou based clusters have come under considerable stress with weaker firms having to exit. Less well known is the industry in Hebei and Shandong. The so-called Gaoyang model—and its resilience through decades of turmoil—is the described by Grove (2006).

[85] 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.

[86] See McGee and others (2007, esp. ch. 6).

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

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 thatcan 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 the intricacies of the research techniques underlying new findings is transferred often through personal communication among a small number of researchers because they are tacit and not ready to be codified.[88] 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[89]. 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"[90] for knowledge networks and clusters. The 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, optimally decentralized, 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.[91] This is being aided by the co-location of R&D and manufacturing in China's leading industrial centers that provide 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 imperiled.[92]

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 example.[93] Moreover, the increasing attention to the quality of schooling at all levels including the programs to develop world

[88] 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.

[89] See Adams, Clemmons and Stephan (2006). 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). Keller (2001a and 2001b) substantiates earlier work by Jaffe and by others.

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

[91] This development noted by Stevenson-Yang and DeWoskin (2005) is unusual and affecting the value of intellectual property, the return on manufacturing and the speed with which manufactures are commodified.

[92] 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 n 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.

[93] See Nature (2011).

class universities[94] will reinforce the benefits from supply (See Yusuf and Nabeshima 2010). Shanghai's top ranked performance in the 2009 PISA tests[95] provided an inkling of what can be achieved through focused attention to raising quality of primary and secondary schools.[96] Similar progress in the quality of tertiary level graduates nationwide would provide a quicker boost to innovativeness and productivity.[97]

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 and penetration of the global market increasingly complemented by the expanding market of domestic urban middle class consumers.[98] A large domesticmarket 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.[99] 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.

Fifth is the pro-business, entrepreneurial culture (staunchly backed by local authorities) in several of China's provinces that 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 innovativeness[100] 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 foreign.[101] This is conducive to innovation—initially most firms are focused on cost innovation and customization for the domestic market but that can change. Companies such as Huawei, ZTE and

[94] 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 andSalmi(2011). See also Kaiser (2010) on how MIT became what it is.

[95] "Top Test Scores From Shanghai Stun Educators 2010"; Science (2010).

[96] 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).

[97] 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.

[98] 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) and Kharas (2009).

[99] 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 2010a).

[100] 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".

[101] This has resulted in corner cutting and environmentally damaging practices. See Midler (2011). The weakening of global demand and a tightening of monetary policy—to contain inflationary pressures—has increased the pressures on smaller firms.

Suntech, can serve as role models for other domestic companies to emulate as to how to become more innovative.

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 technological and process related advances in technology could lead to breakthrough outcomes. Indigenous innovations in marketing,[102] 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 (assuming no easing of innovation pressures), productivity gains in services could begin to equal or overshadow those arising from manufacturing.[103]

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, the testing and adoption of green technologies, environmental quality, affordable housing, and how effectively cities—or entire metro regions—are managed and decisions coordinated. An urban development strategy, the objective of which is to build efficient, green and innovative cities, will create enormous opportunities for innovation in urban planning, metro transportation systems and green technologies. 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 continue to focus industrial attention mainly on exports.[104] 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 control a huge amount of physical assets[105] as well as human talent, and have yet to realize their full potential for innovation.[106] Due to lack of competition or effective corporate governance, some SOEs are indifferently managed[107] and less receptive to strategies that give primacy to growth through innovation.[108] Even when they invest in

[102] 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.

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

[104] 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.

[105] See Hsueh (2011).

[106] Half of the national key laboratories operating in companies certified during the "11th five-year plan" period are located by SOEs owned by the central government. Large SOEs have also been actively participating in national research and development programs and steadily increasing investment in R&D. As mentioned previously, some SOEs have made impressive progresses in upgrading technologies and producing innovative products in fields such as passenger aircrafts, high speed trains, ultra high voltage electricity transmission, and space technologies etc.

[107] The contribution of managerial competence and dynamism to productivity and profitability is analyzed by Bloom and others 2010; and Bloom, Sadun and van Reenen 2009.

[108] See Brandt and Zhu (2010); and Dollar and Wei (2007) on the inefficiency of SOEs relative to their counterparts in other sectors.

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).[109] Growth of total factor productivity in the state sector averaged 1.52 percent per annum as against 4.56 percent per annum in the non-state sector.[110] Extracting high returns from R&D requires managerial ingenuity and experimentation with organizational structures, incentives, an integration of research, production and marketing activities, and a long time horizon. Many small and medium-sized companies complain that some large companies, including large SOEs and multinational nationals, are abusing their market power by favoring their own connected companies and excluding other companies. This inhibits innovation by other companies.

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 sources[111] 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 ethics[112] 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. The tendency to tenure full professors from overseas institutions encourages others to spend their most productive years abroad (Science, 2011, p. 834). Furthermore, although universities have embraced the "third mission" that of commercializing technology, the effects of university industry linkages on technological change have been minimal. Wu and Zhou (2011, p. 2) maintain that "the key role of universities so far centers not so much on cutting edge innovation but on adaptation and redevelopment of existing foreign technology and products . . . the contribution of UILs as a part of university R&D income was largely stagnant in absolute amount and declined sharply as a proportion of the total R&D income during the 2000s. . . . The third mission of universities seems stalled". This is consistent with other observations noted above regarding the current state of innovation in China.

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 government funded or controlled VCs (Zhang and others 2009). This is being corrected, and the amount of capital contributed by governments and solely state-owned investment institutions now accounts for less than 40% of the total amount raised by China's VC industry in 2010. However,[113] more

[109] Although SOEs are less efficient users of R&D resources, they have a higher ratio of invention patents to total patent applications.
[110] SOEs also tend to use four times as much capital per worker on average as firms in the privates sector which is linked to their practice of reinvesting a portion of their profits in expanding production capacity—profits not generally being paid out as dividends or transferred to the Treasury. Easier access to credit from banks further encourages capital spending (OECD 2010b).
[111] 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
[112] 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
[113] See Venture Capital Development in China 2011 (edited by Wang and others, 2011), summary Page II.

support to newly created companies is still required. In the meantime, entrepreneurs continue to lack the mentoring, professional assistance, networking links and market insights, which are invaluable for young firms.[114] Moreover, some VCs are complain that exit is hindered because it takes too long for VC backed companies to be listed in the GEM.

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 access.[115] Innovation policies need to establish greater trust between the government and foreign investors and stronger institutions that validate and operationalize the mutuality of interests. Western European experience starting in the 1960s, suggests that once such trust and faith in institutions is established, technological transfer and spillovers begin to rise and MNCs are ready to localize their latest production techniques. The European experience differs from that of developing economies, however, given China's size and long term importance for MNCs, it can learn from Europe and invest in the institutions, business practices and cultural mores which undergird rapid technological diffusion. Chinese initiatives in these areas will be most fruitful if they are matched by a greater readiness to cooperate on the part of foreign companies in the pursuit of technology development.[116]

Sixth although the benefits of smart (and green) urbanization are becoming apparent to many, much urbanization in China is proceeding inefficiently and untidily characterized by low density sprawl,[117] ribbon development along new highways, real estate speculation, rising costs of housing (with low income households increasingly disadvantaged), 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 are the lifeblood of urban economies and a major source of innovation.[118] 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 technological catch-up. China is putting fairly big bets on a number of technologies even as an innovation system is being pieced together, but without thoroughly evaluating the returns from R&D spending or the merits of recent policies to spur innovation.[119] 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.

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[114] See for example the model for mentoring start-ups introduced by Paul Graham the founder of Y Combinator "The Start-up Guru 2009".

[115] See Hout and Ghemawat (2010).

[116] Chinese companies complain that they face barriers when they try to integrate into global innovation networks. The latest example is the threatened veto by the Committee on Foreign Investment in the US (CFIUS) of the acquisition by Huawei of a small US tech company, 3Leaf (a server technology firm), on the grounds of national security. 3Leaf produces virtualization architecture that enables commodity servers to mimic the capabilities of mainframe computers Huawei eventually dropped its takeover bid. Reuters(2011),"Huawei Backs away from 3Leaf Acquisitions", Reuters http://www.reuters.com/article/2011/02/19/us-huawei-3leaf-idUSTRE71I38920110219

[117] The decline in density as cities expand is an unsettling development worldwide.

[118] See Glaeser (2011).

[119] See the suggestions in Lane and Bertuzzi (2011).

The experience of the former USSR with a planned approach to technology development focused on the defense sector argues for caution. The USSR achieved near parity with the US in many areas of weaponry but because the defense industry and research was isolated from the rest of the economy, it soaked up talent and resources while generating few spillovers and in time contributed to the collapse of the Soviet economy

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

IV. Defining Policy Priorities

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 areas.[120] Recent gains in technological capacity suggest that China is approaching the stage when it can transition to an innovation and productivity led growth path. How quickly it makes the transition will depend on the strengthening institutions that provide incentives to entrepreneurs, scientists and engineers in companies, universities, and research institutions to be more innovative. Thus loosening institutional constraints deserves priority.[121]

This transformation is likely to occur in two stages that will require a varying of the policy focus between the first stage and the next (this division of stages is only for the purposes of illustration). 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 sustain the tempo of competition and facilitate the entry of SMEs, on further reforming SOEs, on the quality of the workforce, on encouraging applied research in firms, and on strengthening the research infrastructure, may be appropriate. During this stage, China should accomplish the ongoing transformation of the planned national innovation system to one that is open, globalized, market oriented and compatible with a market economy. The government needs to increase investment in basic research, push through university reform, raise the quality of S&T skills, and launch large S&T programs targeting some of the weak links in key industries.

In the second decade (2021–2030), China will derive more of its growth impetus from home grown innovations requiring not just the generation of ideas through cutting edge basic research—with risky blue skies research supported by the state—but also the harnessing of these ideas by dynamic Chinese multi-national firms which are technology leaders in their own particular areas, committed to achieving competitiveness through innovation and able to engage in technological exchanges and partnerships with foreign firms on equal terms[122]. In attaining such leadership, Chinese companies will necessarily be harnessing worldwide innovation resources much like their foreign counterparts.

As we indicate earlier in the chapter, policies for the first stage necessarily overlap with second. The difference is in emphasis. Several of the policies listed and discussed below, are front-loaded 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 microstructure of the business sector, which is why a competitive environment and investment promoting macro-stability are of paramount importance. National technology and innovation policies will need to be complemented by urban policies that recognize the vital role of cities in advancing ideas, extracting the maximum mileage from existing general purpose technologies and helping germinate new green technologies. The roles of the various entities involved are further spelled out in Annex Tables 16.

1. Increased market competition aided by greater national market integration which promotes specialization of production and research activities
2. Making enterprises play a pivotal role in the national innovation system
3. Building national research consortia and networks

[120] A comprehensive treatment of innovation policy can be found in World Bank (2010).
[121] Wu Jinglian (2003) and Chen Qingtai (2011) elaborate on the primacy of good institutions for technological progress and innovation.
[122] The off-shoring of R&D is set to continue (Dehoff and Sehgal 2009). See Carlsson (2006) on the internationalization of R&D and on the contribution of national institutions to the process of globalization.

4. Improving the productivity and quality of tertiary level education with the help of IT and other innovations
5. Strengthening technical and vocational skills to fully exploit technical advances
6. Tighter integration of a more productive national innovation system with the global innovation system
7. Sustaining an increase in R&D spending to raise the productivity of national innovation system
8. Enabling policies and rigorous evaluation and refereeing of research programs to raise the quality of outcomes and to maximize productivity benefits
9. Increasing access to risk capital and mentoring of start-ups and SMEs by suppliers of venture financing
10. Effective and disciplined use of government procurement to stimulate innovation

1. Deepening reform to develop a competitive market

A competitive market environment is necessary condition for steady improvement in productivity. This entails the opening of product markets, subjecting SOEs in the pillar industries to competition from private firms[123] and the fair and effective enforcement of laws regulating competition and protecting intellectual property as well as consumer rights.[124] It also extends to competition and ease of mobility in factor markets. 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, promote the growth of dynamic SMEs,[125] and induce the SOEs to raise their game (and pave the way for further reform). Greater national market integration would 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. It would mean intensifying the degree of competition and churning among firms,[126] encouraging firms to compete on the basis of technology, and promoting much needed regional or local industrial and research specialization.

Competition and market integration is inseparable from the efficient pricing of fossil fuels (with carbon taxes added to reflect externalities), 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. This will also generate pressures to upgrade technologies, which some western countries have done to good effect.[127] Strengthening the industrial extension system and providing smaller firms with easier access to laboratory, metrology, testing and certification facilities would facilitate meeting these standards by smaller firms. The German Fraunhofer Institutes and the TEFT system in Norway

[123] See Owen, Zheng and Sun (2007).

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

[125] Rising costs, tightening credit and weakening of export demand has dampened the performance and reduced the profitability of China's 2.5 million privately owned SMEs. The future contribution of this vital sector will depend on a moderation of these recent trends. "Rising Costs threaten China's SMEs" (2011).

[126] 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).

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

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, testing equipment, assistance for obtaining product certification and the creating of web pages for purposes of advertising, plus other services.

2. Making enterprises play a pivotal role in the national innovation system

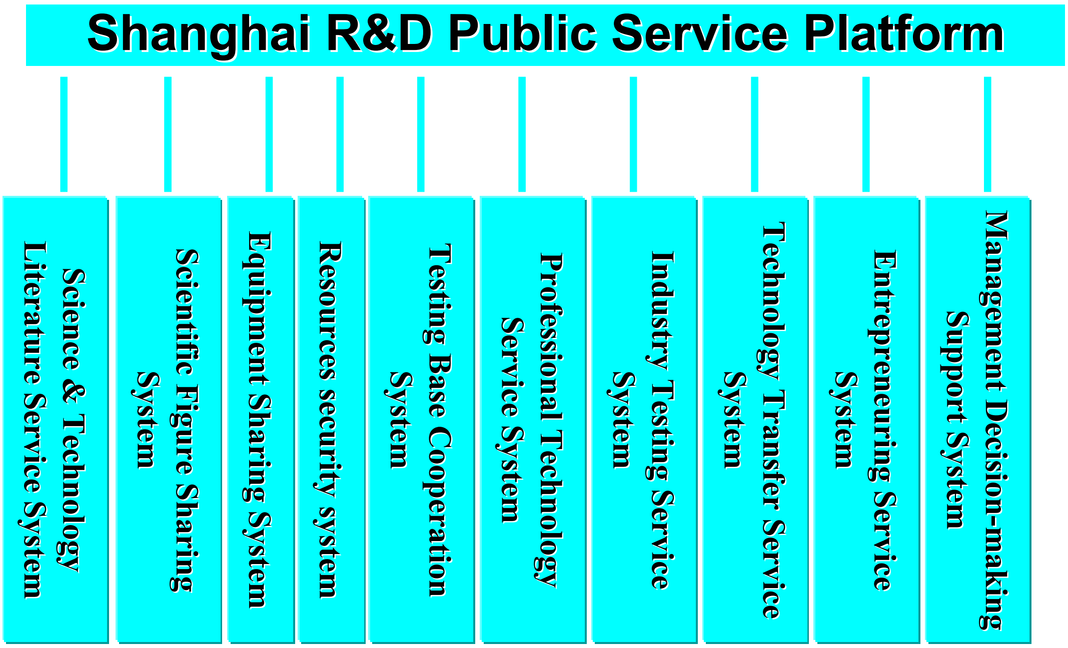
Innovation is essentially about creating more wealth by discovering and using newer methods. All the economies successful in innovation, be it long time innovation leader USA, or successful late comers such as Japan and South Korea, companies have been at the center of the national innovation systems. Most of the applied research and innovation of consequence for the economy is done by firms[128]—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 environment to pursue interesting ideas (Shapin 2010).[129] 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.

Government can support enterprises in developing technological capabilities and producing innovative products by establishing research and development platforms for the use by those companies. In China, there are a range R&D platforms and business service providers such as engineering research centers and productivity centers, but many of them lack the market orientation, the close involvement of potential employers in the design and training of curricula and suffer from shortages of funding and of experienced trainers. 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 that 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.

[128] 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.

[129] 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". The experience of successful firms in China and abroad provides useful clues to how the innovative teams within firm interact with the policy and institutional framework in which they operate. A number of Chinese case studies are presented by Tan (2011). Case studies of foreign firms can be found in Herstatt and others (2006); and Boutellier and others (2000).

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.

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 persists.[130] 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 enterprises so as to embed a culture supportive of innovation.[131] 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 firm,[132] 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 and the corporate culture, China may struggle to absorb technology[133] at the desired pace and make the leap from catch-up to a regime of steady innovation.

[130] 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.

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

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

[133] 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.The importance of a corporate culture of innovation, is empirically supported by Jaruzelski, Loehr and Holman (2011).

3. To build nation-wide research and development networks

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 consortia[134] tasked with disseminating the latest technologies and advancing technology in areas where they have an existing or nascent comparative advantage.[135] Such consortia have been sponsored by governments in Japan and the U.S. and they can help China develop more "global challengers" including from the inland metro regions. Successful regional innovation systems are associated with universities which conduct some of the upstream research and generate ideas, a mix of smaller firms that often take the lead in introducing new technologies with mentoring from venture capitalists and angel investors, and larger firms with resources to perfect, scale up, and improve and market the commercial outcomes of these technologies.[136] 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 example[137] but one that will hinge on regional innovation policies actively pursued by local governments which provide the incentives and build the institutions tailored for local needs. Inland cities with a research orientation would benefit from a focus on industries and depending on what kind of activities achieve prominence, governments will have to act accordingly: developing a research based bio-tech cluster will require very different policies from an engineering or a food processing or a white goods cluster.

4. To improve the quality of Chinese universities

China's universities are graduating millions of students each year to meet the needs of the knowledge economy.[138] 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 temporary.[139] 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 pedagogical techniques which favor lecturing over discussion

[134] 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.

[135] 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".

[136] For China's regional innovation systems, see Research Group on Development and Strategy of Science and Technology (2011); Liu and others (2010) "Construction of a balanced regional innovation system".

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

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

[139] "China's Army of Graduates Struggles for Jobs" (2010).

and greater classroom involvement of students;[140] 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 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 innovations[141] of their own in order to provide customized education for a vastly larger body of students at an acceptable cost[142]—although it must be recognized that there is no simple technological fix.[143] Universities are more likely to embrace change 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 (especially now that great advances in video links have advanced to a point where a virtual seminar is becoming a reality) and new pedagogical practices.[144] 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 teaching,[145] 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 maturity.[146]

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),[147] 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 programs[148] and set up specialized, well staffed research institutes. The quality and international composition of the faculty will also influence the degree and fruitfulness of university industry collaboration.[149]

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[140] China's numerous business schools which have made great effort to imitate western schools and attract academics from abroad, still lag behind on a number of counts and managerial talent remains in short supply. See "China's schools must make the leap forward" FT Sept. 26 2011.

[141] See Christensen, Horn and Soares (2011); and Christensen, Horn, Caldera and Soares (2011).

[142] See for example, Zhong (2011).

[143] For example, the initial enthusiasm with cheap laptops for children in developing countries is being tempered by the realization that it is only likely to produce any results if it is combined with teacher training, a redesigning of the curricula and an overhaul of weak school systems. The mixed results from the use of ICT in schools are also highlighted by Machin, McNally and Silva (2007) who observe that the teaching of Science and English benefitted more than the teaching of Mathematics.

[144] Linking university funding on a sliding scale to the quality of outcomes, is one way of spurring innovation.

[145] 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).

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

[147] 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).

[148] 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.

[149] Perkman, King and Pavelin (2011).

An important contribution universities can make to innovation is to make discoveries and generating ideas by conducting basic researches. Universities also serve as a breeding ground for entrepreneurs[150] 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.[151]

5. To strengthen vocational training

The development of high tech industry envisaged by the 12 FYP depends upon an increased supply and upgrading of technical skills through in-house and vocational training schools of a vast range of technical skills to staff factories, engage in technically more demanding tasks as innovation ratchets up the level of industrial complexity, 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 opting for general education. Striking a better balance between the general and the technical would seem to be warranted.

6. To develop an open innovation system

Investment in R&D facilities by MNCs is on the rise and needs to 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 MNCs[152] 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 system.[153] 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

[150] 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.

[151] Wu and Zhou (2011) suggest that greater autonomy for universities, allocating more of the research funding to the leading research entities and the leveraging of science parks adjacent to research universities might yield attractive dividends.

[152] 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".

[153] 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

are in the throes of reform)[154] and effective protection of IP will expedite the growth of China's innovation capabilities (de Vaal and Smeets 2011). Gwynne (2010, p. 27)[155] 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".[156] Legal developments in the form of specialized IP courts with professional judges and a sure in the number of cases is changing the picture. It is also undeniable that China has made substantial progress in IPR protection to further its ambition becoming an innovative country following the launch of reforms in 2008 to support the creation, utilization, management, and protection of IP. China probably is the only country in the world that IPR violations can be criminalized. As more and more Chinese firms file court cases against violation of IP rights by other Chinese firms, the awareness of IPR protection will be further raised and protection rendered more effective.[157] Furthermore, the Chinese government has recently relaxed some restrictions regarded as unfairly imposed on MNCs with regard to government procurement, which should encourage MNCs to establish R&D centers in China. Chinese government should also encourage home grown MNCs to participate in international R&D be integrated into global innovative networks.[158]

7. Strengthen basic research to sustain continuous support for innovation

Central and provincial governments in China are seeking to enlarge the share of basic research[159] in universities and research institutes as well as to raise the profile of R&D in firms thereby building research capacity throughout the country. They are more likely to succeed by committing a sufficient volume of funding and ensuring the continuity of funding, with the help of an enabling macro policy environment, and through a systematic evaluation of programs. 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 with private companies and this enabled many companies to come up to speed and become innovators themselves.

[154] 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).
[155] "The China Question" (2011).
[156] Suttmeier and Yao (2011, p. 19) observes, "Piracy and other forms of infringement remain extensive. Chinese culture still seems to have trouble valuing intangible assets. Elements of techno-nationalism in China's innovation policies . . . encourage suspicions that that the country's IP transition may not be one of harmonization. And it is difficult to see how an internationally harmonized IP system can exist where the concept of rights is so weakly established".
[157] On rules, policy directives and statistics, see SIPO: http://www.sipo.gov.cn/.
[158] Chinese officials and some companies CEOs complain that, due to certain international treaties that date back to the cold war era, such as "The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Good and Technologies", Chinese companies are denied of the right to purchase some technologies or high-end equipments. See Xue Yanping "The Wassenaar Arrangement and EU's embargo on high-tech export to China", http://ies.cass.cn/Article/cbw/ozkj/201101/3394.asp.
[159] 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).

In order to maximize the returns from outlay on R&D over the longer term, the enabling characteristics of the domestic macroeconomic and business environments will be decisive. Raising R&D spending to 2.2 percent of GDP by 2020 as the government proposes will have a minimal impact on productivity unless enabling policies reinforces it. 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 higher R&D need have only a limited effect on growth is also apparent from the experience of Sweden, Finland and Japan (see Lane 2009; Ejermo, Kander and Henning 2011). Thus a one-percentage point of GDP increase in R&D will be one strand of China's growth strategy.

8. Good research is inseparable from a stringent and disciplined process of evaluation and refereeing of research programs and findings

This is a difficult but unavoidable activity. As Lane observes (2009, p. 1274), "The relation between science and innovation is nonlinear in nature, with complex outcomes that can vary substantially by discipline and are subject to considerable time lags . . . Innovation is nonlinear because the demand side and the supply side of ideas are inextricably intertwined". It is an activity requiring initiative from the research community, particularly in strengthening research ethics[160] and instituting strict penalties against plagiarism and strengthening the independence and quality of the refereeing process.[161] 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[162]) which promise to break new ground. Such projects should be evaluated by their potential for transforming a subfield. More broadly, the management and evaluation of R&D in China will call for considerable enlightened strategizing and management by public agencies.

The developments of innovation capacity in China since the mid 1990s has involved multiple agencies and numerous policies have been introduced. Looking ahead, with the focus on innovation sure to sharpen, the tempo of policymaking can only increase and the economic outcomes will depend substantially on the quality and timeliness of the policy interventions. If past experience from other countries is a reliable guide, these policies will be multi-agency, multi-disciplinary and will rely upon a mix of tax, fiscal, financial and regulatory instruments. Good policies will depend upon:

- Strong leadership by the CPCC/State Council, by strengthening the leading group on Science, Technology and Education, headed by the premier which would have the requisite authority;
- Direct and consistent involvement of the NDRC, MOF and MOST, the key ministries involved with innovation policies, and effective coordination of their roles;
- Effective horizontal communication and coordination among other major ministries engaged in the making and implementation of ST&I policies, such as the Ministry of Education, the Ministry of Commerce, the Ministry of Health, the Ministry of Industry and Information Technology, the Ministry of Agriculture and others. The leadership role of a CPCC leading group[163] would ensure that past fragmentation of decision making among agencies each of which pursues a narrow policy agenda within its own particular silo, and the conflict

[160] 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.
[161] Refereeing all too often relies on the "old boy network" which predetermines the outcome. Many referees drawn from scientific fields also struggle to cope with socio-economic effects of new technologies.
[162] See Bonvillian and Van Atta (2011) on the application of the DARPA approach to innovation in the energy sector.
[163] See Liu and others (2011).

among roles and mandates is minimized and greater policy coherence and effectiveness is achieved. The weight of leadership and the engagement of the NDRC and the MOF would also increase the commitment of sub-national governments[164] to the innovation agenda and lead to the strengthening of regional innovation systems;

- Leadership and coordination must go hand in hand with a concerted effort to raise the technical and implementation skills of the government bureaucracies tasked with driving the innovation strategy. It almost goes without saying that the growth of innovation capabilities will demand considerable farsightedness, agility and innovativeness on the part of those responsible for guiding and managing a highly complex endeavor during a crucial stage of gestation. The quality of the bureaucracy matters everywhere, however, given the large role played by the state in China, the importance attached to building innovation capacity in the shortest possible time and the vast resources being invested, the caliber of the bureaucracy takes on an added significance;
- The experience of the most innovative countries—such as Finland, Israel, the U.S. and others—none of which can boast an unimpeachable innovation system[165] has underscored the contribution which a sound process of evaluating research related spending can make to the design and conduct of innovation policies and to raising of system productivity. Economists have generally tended to give high marks to R&D spending claiming that it generates exceedingly high rates of social and even private returns usually higher than spending on fixed assets.[166] But on closer scrutiny, it appears that many of these claims might be exaggerated. Ben Martin the editor of *Research Policy* observes that not infrequently, "there is some PR (public relations) rather than rigorous research involved."[167] Measuring the inputs and outputs of research is not a trivial exercise. The benefits from research are uncertain, variable and accrue over a long period of time. Moreover, the bulk of the returns take the form of spillovers for which there are no good metrics. The problem is especially severe with basic research. There are costs to research results and their assimilation, which can come to light much later and need to be factored in. For example, when new medical technologies extend the lives of elderly patients, this imposes costs on society; nuclear power has imposed clean up and disposal costs; and many defense technologies have not been unmitigated blessings. Collecting data on inputs and outputs from myriad and disparate sources, making it consistent and readable is an additional and daunting task. Once the data is gathered, selecting an appropriate methodology presents a further challenge.[168] But all this is unavoidable in view of the sums involved and the need to obtain the greatest possible productivity mileage from public spending on the innovation system. The lesson from advanced countries is that it is better to start early by putting in place a system to rapidly evaluate research spending, to absorb the learning promptly into the policymaking process and to be ready to make corrections or terminate programs which are not producing results. China is at the stage where it can begin building in the elements of an evaluation process into its emerging innovation system learning from others[169] and fully utilizing the latest data gathering, storage and ana-

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[164] Local governments assign the highest importance to GDP growth, implementing innovation policies is a secondary concern.

[165] See www.evaluation.fi for a measured assessment of the innovation system in Finland widely viewed as having one of the best performing innovation architectures.

[166] See Weiser (2005) for a survey and Lach, Parizat and Wasserteil (2008) for an evaluation of returns from investment by the Israeli government in R&D.

[167] "What Science is Really Worth" Nature 2010, June, p. 683.

[168] The difficulty faced by the U.S. in finding satisfactory answers for legislators as to the cost effectiveness of the Advanced Technology Program (ATP) and the Small Business Innovation Research (SBIR) highlights the difficulties governments face as they craft innovation policies which will deliver the sought after growth and welfare dividends.

[169] See the extensive and many faceted discussions of evaluation methods in Shapira and Kuhlman (2001). The STAR METRICS project is one example of a comprehensive approach to evaluating the full economic, scientific and societal benefits of research.

lytic technologies that are becoming available and that promise to make a difficult task more manageable.[170]

9. Develop multi-layered capital market to support innovation and start-ups

Rising demand for risk capital calls for an increase in supply. 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. Moreover, 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. Nonetheless, 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 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 (12 percent of GDP in 2010) 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. To facilitate exit for VCs is as import as raising venture capital for start-ups and innovative firms.[171] So far, small and medium sized companies only have limited choices to raise capital by listing in stock exchanges, which normally takes a long time, and this has affected VC investment.

10. Making better use of demand-side policies

Demand-side policy instruments such as government procurement and the setting of standards for equipment and services, combined with adequate efforts to guard against protectionist and rent seeking activities that undermine market competition and discourage high-tech FDI, will stimulate the demand for innovation.[172] 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 National People's Congress adopted the Law 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 need to be fully recognized and reflected in government policies: (a) the risk of turning the government procurement instrument into one that protects national and local products from international and national competition; (b) the risk of the government becoming a passive taker of what domestic suppliers offer, rather than a demanding buyer of technologically sophisticated products.[173] 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

[170] Massive data assembly and number crunching on a scale not imaginable a few years ago is now a reality and being widely harnessed by industry to study all kinds of behaviors and processes. These technologies could make it easier to chart innovation policy and to cope with its many uncertainties—also with the use of visualization techniques. See Elmer (2004); and Ayres (2007).

[171] See Guo, Zhang, and Li (2000); Guo (2009).

[172] See Liu and Zhang, 2008; Zhang, 2007.

[173] Zhang, Mako and Seward (2008).

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 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.[174]

[174] Ibid.

V. Some Key Areas for Innovation

As per capita incomes rise, China's spending on healthcare will also increase in parallel. The health care sector will become an important sector for China's economic growth and social development. In addition, as hundreds of millions of people emigrate from rural areas developing green, smart and innovative cities will be an important pillar for China's growth through innovation.

1. Innovation in Healthcare

The salience of healthcare in the Chinese economy is certain to increase and innovation will be an important mechanism for controlling costs while raising quality and expanding access to healthcare. Healthcare in China confronts a "perfect storm" with steeply rising social and financial costs that could become a huge burden on the nation in a handful of decades. To quote from a Lancet editorial (October 25th 2008, vol. 372, p. 1437), "The population demographics are uneven, exaggerated by rapid ageing, as a result of the single child policy, and by the large number of highly mobile workers within the country. The health infrastructure is variable, with world leading medical centers in the populous east of the country, whereas more rural areas lack basic sanitation. Despite better control, infectious diseases still account for considerable morbidity with an ever-present danger of new outbreaks. Alongside communicable diseases are the increasing burdens caused by the diseases of affluence and changing lifestyles. Meanwhile the ability to deliver care is compromised by an uneven distribution of human resources and the loss of doctor to other professions. In addition to the breadth of the challenges, the size of the task is enormous. A Chinese man smokes one in every three cigarettes. 177 million adults in China have hypertension but few receive effective treatment". The inexorable march of non-communicable diseases is heightening concerns, as these are now responsible for 80 percent of all deaths and 69 percent of the disease burden—higher than in the advanced countries—and they threaten to significantly erode China's economic gains (World Bank 2011). David Cutler (2003) has estimated that OECD countries can expect healthcare costs to rise by 5.7 percent of GDP just on the basis of demographic and technological changes. The increase could be greater in China given its stage of development, rising incomes, changing lifestyles and its epidemiological profile. Containing healthcare costs while providing modern healthcare to the entire population promises to remain a long-term policy objective. And the experience of advanced countries points to the urgency of policy intervention, before institutions have had time to solidify and strong vested interests have become almost politically invincible, as is the case in the United States but also in Europe and Japan, and the system acquires an immense status quo bias (Starr 1984, 2011).

Clearly innovation is only a part of the answer, and in fact some of the cost escalation[175] is directly attributable to advances in pharmaceuticals, diagnostic devices, medical implants and others. But there is also no doubt that technological improvements are also behind some of the advances in the quality of healthcare and increasing longevity (Lichtenberg 2008, 2010, 2011). Among the innovations that are likely to play a major role in the future, advances in preventive medicine which reduce the risks from communicable diseases, ameliorate the effects of chronic ailments, bring about changes in lifestyles and ensure that the majority of the population has access to clean water and good sanitation, deserve the most prominence. Some of these will involve bio pharmaceutical innovations but many others will play a role. Digital medicine is set to greatly expand its contribution by revolutionizing billing, ordering, record keeping and sharing, and medical administration. Digital medicine is also transforming the access to medi-

[175] One explanation is that the incentives for innovation by providers are much too generous particularly in the US and the checks on cost escalation through the excessive use of new technologies some of dubious efficacy are too weak. See Callahan (2009).

cal information, communication between doctors and patients and the monitoring of patients by providers. Advances in distance medicine is a medical assets multiplier whose potential is only begun to be tapped through new diagnostic and other devices as well as through the outsourcing of diagnosis. The potential of digital technology, how it can be assimilated (and the advantages of early action) and the many ethical, procedural, administrative and financial hurdles, are lucidly discussed by West and Miller (2009).[176]

ICT can also help to contain costs by enabling a much more exact measurement of total costs of care than is the case currently. Providers and insurers have only a very rough idea of the costs of caring for a patient and now are in a position to track the type and amount of resources used over the course of a medical condition (Kaplan and Porter 2011).

Christensen, Grossman and Hwang (2009) highlight another aspect of innovations in the bio pharmaceutical and diagnostic fields with potentially disruptive and cost reducing effects. This is the rise of so-called precision medicine tailored to the unique genetic profile of each patient which would sharpen the accuracy of diagnosis and ensure that each ailment is treated with the medications calculated to have greatest effect and the fewest side effects.[177] The cost savings from this could be large.

To strike the best balance between the quality of healthcare and costs, China will have to strive after medical innovation that is tempered by effective regulation (which minimizes red tape, optimizes incentives for providers, and fully harnesses ICT) and competition among providers on results so that more patients migrate to better providers. Porter and Teisberg (2006, p. 7, 13) note that "Good quality is less costly because of more accurate diagnoses, fewer treatment errors, lower complication rates, faster recovery, less invasive treatments, and the minimization of the need for treatment. Competition on results to improve patient value is an irresistible force for transforming the healthcare system without the need for top-down government intervention". Greater competition in healthcare would be very much in tune with the overall strategy to build a more competitive economic system.

2. Building Green, Smart and Innovative Cities

Investment in technological capacity is more likely to result in a flourishing of innovation in a competitive environment and in "open" cities.[178] Learning from its experience with rapid industrialization in the 1980s, China initially sought to enlarge technological capacity in a small number of coastal cities (notably Shenzhen—and other cities in the PRD—Shanghai, Guangzhou and Beijing) with the help of FDI, imported equipment embodying new techniques, licensing and reverse engineering. 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 the increasing emphasis on achieving technological parity with the West and on greening growth to improve quality and minimize environmental costs, offers an opportunity to develop the innovation capacity of the coastal and some of the inland cities and in the process, increase the productivity of R&D expenditures.

Innovative cities rely upon the quality of human capital, on institutional mechanisms and basic research of a high order for generating ideas and on ways of debating, testing and perfecting these ideas and transforming them into marketable products. The innovative city achieves

[176] There is a vast literature on e-medicine and on distance medicine in the technical journals.
[177] A profiling of patients would initially be based on the patient's genome although later it could be done through the transcriptome. This approach would enable the medical establishment to anticipate and prevent diseases to which a patient might be susceptible in the future and to develop drugs for currently incurable diseases.
[178] See also Hu (2011, p. 97).

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).

The leading global innovative hotspots are open to ideas and thrive on the heterogeneity of knowledge workers drawn from all over the country—and the world.[179] 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. 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 validating 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 root.[180] Connectivity via state of the art telecommunications and transport infrastructure (airports in particular)[181] 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.[182]

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[183] and account for a sizable share of the global market.

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.

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.

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

180 See for instance Henderson (2003); and Henderson (2010). Carlino, Chatterjee and Hunt (2007); and Carlino and Hunt (2009).

181 See Kasarda and Lindsay (2011).

182 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.

183 Demonstrated by high rates of patenting.

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.

The S&T capacity of China's coastal cites 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. 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 ARM[184] and Cambridge Consultants served as the anchors for the electronics cluster in Cambridge U.K. Several cities such as Chengdu, Shenyang and Chongqing[185] 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.[186] 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 focuson industry in the interests of specialization and on the quality of the environment.

Greening Urban Growth

Economic growth that is largely urban driven must be rendered climate friendly. Hence the "greening" of urban growth is becoming a priority in China and worldwide. Although the precise meaning of green growth remains somewhat elusive, it points to the possibility of achieving sustainable urban development through a virtuous spiral of innovations. At the core of green growth is the assumption that the energy, natural capital and emissions intensity of GDP can be contained or reduced as economies expand. But the hope is that if greening can be mainstreamed much more can be achieved: a green growth strategy should lead to development of and investments in low carbon technologies and infrastructures that bring about a green industrial revolution creating the jobs and raising incomes without the negative externalities associated with the fossil fuel based growth of the past two centuries, and greening can contain the trend change in the climate. An exploration of the possibilities is still at an early stage and hemmed in by the prevalence of entrenched technologies but even now it is obvious that if the revolution is to succeed, much will depend upon the initiatives taken by cities and how effectively these are implemented.

To realize the potential of green urban growth, a conceptual framework can usefully provide the scaffolding for policies—national and local. In this context, an intersection of two concepts pertaining to general purpose technologies and to agglomeration economies, can serve to identify and elaborate actions to promote green growth.

Long cycles of growth augmenting technological change are associated with the emergence and diffusion general-purpose technologies (GPTs) which have protracted and economy wide effects. A GPT has three characteristics (See Bresnahan and Trajtenberg 1996):

1. *Pervasiveness*—It should spread to most sectors.
2. *Improvement*—It needs to evolve and improve over time with users benefitting from steadily falling costs.

[184] 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.
[185] 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".
[186] However, most of the more than 600 R&D centers established by MNCs are in the coastal cities, chiefly Shanghai and Beijing.

3. *Innovation spawning*—The GPT should promote invention and provide the soil for new products, processes and related organizational and institutional changes.

Steam, electricity, the internal combustion engine and now IT, are the emblematic GPTs[187]. Each was and is responsible for urban industrialization extending over several decades, requiring a massive volume of investment. The effects were not limited to a single sector, instead GPTs unleashed innovations that diffused through and energized the entire economy. The innovations shifted the production frontier, triggered sustained investment in new products, business models and modes of production and served as the foundations of long term economic growth. Starting in the 1970s, the benefits from IT began filtering through the global economy and very likely will continue to stimulate innovation and productivity for another decade or two. However, with the looming threat of climate change from accumulating GHGs largely released by urban centers (up to 80% of the total) and the increasing press of energy and resource scarcities, there is a need for energy and resource utilization systems that in conjunction with IT, will gradually transform the entire urban economy with seismic network effects similar to those that arose from the displacement of wood as the primary source of energy by coal.

A green growth strategy can potentially reinforce the productivity gains from urban agglomeration by introducing technological innovations and minimizing the productivity eroding effects of urban sprawl, land use distortions, inattention to the design of cities, inefficient services and infrastructures and transport systems catering to ever increasing auto-mobility. Green urbanization suggests a number of policy directions:

- With respect to urban design, it would put a premium on the compactness of cities and mixed-use neighborhoods with due attention to and investment in public transport systems, green spaces and recreational amenities so as to reduce energy intensity as well as environmental pollution.
- It would seek to more fully realize the returns from urban real estate and supporting infrastructures while remaining mindful of urban congestion and without compromising individual intra-urban mobility and the quality of urban life.
- To deliver on its growth potential, green urban agglomeration would need to be hospitable to the continued vitality of existing industrial activities (while providing incentives for the greening of these activities) and to the emergence of new industrial clusters producing tradables so as to generate net employment and a flow of exports.
- It would support the growth of urban industries and services producing for the green economy: the adoption of energy and resource conserving technologies (e.g., smart grids, energy efficient housing and consumer products) backed by standards, regulations, pricing and procurement policies plus consumer education campaigns which bring about a shift in preferences; of technologies controlling emissions and waste; and of techniques promoting recycling and disposal to minimize environmental impacts. To this end, green urbanization must strive after a mix of entrepreneurship and specialized skills to research, produce, transport, install and service the technologies and products driving green cities. Thus the productivity of green urbanization would be even more closely related to technological change guided by market and non-market signals, as well as the quality and skills of the urban workforce.
- Exploiting the sources of green growth to the full will be a function of creative urban and national bureaucracies committed to a green agenda and able to respond quickly to new information, formulate and implement policies and achieve the necessary interdepartmental and inter-jurisdictional coordination the lack of which all too often stifles change. More so than in the past, the bureaucracies will need to be prodded by a vigilant, informed and networked civil society to set targets, learn from best practice, benchmark and produce results.

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[187] Jovanovic and Rousseau (2005), http://www.econ.nyu.edu/user/jovanovi/JovRousseauGPT.pdf

While the possibilities inherent in green technologies and in green urbanization deserve serious attention, good policies are difficult to identify and will only emerge once a number of questions have been empirically addressed:

First, it is important to ascertain the practicality of the green growth concept for policy-making purposes and how compatible it is with other views of economic growth. Moreover, given that the current share of green industries (producing "environmental goods") is small (it is about 1.5% of total employment in OECD countries), what would it take for the green economy to become a significant growth driver within the next two decades?

Second, it is desirable to canvas international experience with net job creation (are green jobs new jobs?) and local industrialization, and productivity gains at a city level of policies aimed at: increasing energy efficiency and conservation (smart meters); substituting renewable with fossil based energy and developing advanced storage devices for use with intermittent power generating sources; retrofitting existing structures (residential and commercial) and (power, water supply, transport and sanitation) systems with new green technology based equipment; and managing ownership and use of private cars (with the help of sensor technologies and ICT).

Third, China needs to learn from domestic and international sources about the more effective application of policy vehicles/instruments to support green urbanization and how might they be improved. These include:

- Public bureaucracies tasked with devising, implementing and monitoring green strategies;
- Local taxes, fees other charges to manage energy and resource consumption as well as raise revenues some of it for green infrastructure and development. And the use of local or national carbon markets to manage energy consumption;
- Zoning, land use, floor area ratios, real estate/property taxes (to limit urban sprawl) and urban design to arrest current trends, promote compact, green development and begin transforming legacy urban infrastructure;
- Subsidies, tax and other incentives in support of specialized training to enlarge the pool of relevant skills, provide incentives for research and encourage start-up activity in green industries;
- Standards and codes for structures and equipment; eco labeling; incentives to use green energy; and education programs to stimulate use of green technologies;
- Fiscal instruments and financing vehicles (public/private, foreign funded) to raise the capital for the substantial up front spending needed to jump start green development, implement green urban projects, many with long payback periods, and maintain the momentum of green development over the long haul;
- Technology parks, seed capital and tax exemptions to induce the formation of green industrial clusters.

Finally, it is important to take a measure of green technologies likely to mature over the next fifteen years most of which are already known and judge whether a new green general purpose technology comparable to the Internet and the internal combustion engine is emerging which will impinge upon many areas of activity and result in long term productivity gains of the magnitude associated with the diffusion of ICT. This would help clarify whether there is an accumulating fund of reasonably tested and cost effective low carbon/green technologies (e.g. in the construction industry and related to the development of smart transport systems) waiting to be exploited or are most technologies (e.g. light weight electric cars connected by a mobility internet) still at an early stage or as yet undiscovered? In other words, tomorrow's green electrons should not just be expensive versions of today's brown electrons: greening should be part and parcel of a quantum leap in technology and productivity. The question to be asked is: How quickly could the most promising and relatively cost effective technologies be scaled up given financing availability, technological expertise, industrial capacity, public readiness to adopt new technologies and lifestyles and constraints posed by legacy infrastructures, vested interests and mainstream technologies?

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 policy will provide most of the impetus in the first stage but success will hinge on the quality of the workforce, the initiative and strategy of firms, the emergence of supporting services and the enabling 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. Making SOEs more innovative will contribute significantly to China's sustained growth. 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%
424	5	Drug, Bio-Affecting and Body Treating Compositions (includes Class 514)	2.8%
707	6	DP: Database and File Management or Data Structures (Data Processing)	2.5%
455	7	Telecommunications	2.1%
438	8	Semiconductor Device Manufacturing: Process	1.9%
375	10	Pulse or Digital Communications	1.7%
532	14	Organic Compounds (includes Classes 532-570)	1.4%
435	17	Chemistry: Molecular Biology and Microbiology	1.1%
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%

Source: China State Intellectual Property Office.
**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.

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

(%)	Guangdong			Beijing			Zhejiang		
	1996 - 2000	**2001 - 2005**	**2006 - 2008**	**1996 - 2000**	**2001 - 2005**	**2006 - 2008**	**1996 - 2000**	**2001 - 2005**	**2006 - 2008**
Manufacturing	***29.03***	***35.71***	***32.84***	***14.65***	***10.64***	***6.36***	***51.22***	***48.98***	***42.98***
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, Machinery for Cultural and Office Work	0.40	0.46	0.49	0.58	0.43	0.21	1.23	0.87	0.66
Manufacture of Artwork, Other Manufacture	0.87	1.14	1.05	0.28	0.20	0.20	1.84	2.09	2.01
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 Transmission Services	0.25	0.43	0.55	0.74	1.05	0.92	0.18	0.20	0.21
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***	***12.77***	***17.38***	***20.13***	***6.45***	***6.12***	***8.68***
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	12.05	16.71	19.41	6.30	5.91	8.30
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 Development	0.30	0.63	0.92	0.63	0.79	0.75	0.17	0.18	0.22
Technical Service	1.35	1.78	1.75	2.67	2.93	2.74	1.05	1.30	1.23
Scientific Exchange and Disseminate Service	0.32	0.45	0.48	3.32	3.72	5.12	0.50	0.72	1.17
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 Entired 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	6.996
	Guangxi	1.296	1.508	2.158	
	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	*Region*	*1.436*	*1.625*	*2.199*	*2.939*
	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

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

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		1494	Shaanxi	6087
Jiangsu	87286	Inner 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 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	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	Expenditure 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 Enterprises (unit)	Share	R&D Personnel (thousand)	Share	Expenditure on R&D (bn)	Share	Number of Patents 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 NIS

Entities in NIS	Primary Objectives	Incentive mechanisms	The actions that the entities should and could take	Institutions and Policies that could influence the behaviors of the entities
Domestic Enterprises	Sustained profitability; Long-term competitiveness	Market competition as driving force for innovation (Schumpeterian innovation)	Improve management; Purchase of technology; Long term R&D investment; Research networking; Recruit talents	Promote effective competition; Protection of IPR; Enhance the supply of human resources; Encourage entrepreneurship Tax incentives for R&D investment; Demands - side incentives;
Foreign funded enterprises	Sustained profitability; Long-term competitiveness	Market competition as driving force for innovation (Schumpeter innovation)	Purchase technology from the parent company; Launch local R&D activities; Hire local talents	Promote a fully completive environment; Credible IPR protection; Enhance the supply of human resources; Incentives for establishing R&D facilities and investing in R&D
Universities	Cultivate talents; Frontier research	Teaching evaluation; Funds granted from the state; Peer pressure	Reform education philosophy; improve education methods; recruit top grade faculties; Encourage free thinking and independent research	Grant more autonomyto universities; Reform the evaluation and appraisal system of university; Reform the grant award and evaluation system of major R&D project
R&D institutions	Applied and basic research; Cultivate talents	Funds granted from the state; Peer pressure	Design effective internal incentive mechanisms; recruit first grade scientists and engineers	Reform grant award system for major R&D projects; Increase funds for hiring experts and Post-doctorial fellows
Engineers and scientists	Wealth creation	Professional discipline; Peer pressure	Self-motivated; lifelong learning; Perseverance	Reform grant award system for major R&D projects; Encourage freedom in research; Reform the appraisal and compensation system
Industry associations	Serve companies	Trust of the firms; Recognition by the society	Promote the cooperation between firms; Improve communications between governments and industry; Facilitate R&D alliances	Grant more autonomy to industry associations

Financial institutions	Profit maximization; Long-term competitiveness	High profits; market competition; Comply with the laws and regulations	Professional investment team; Good risk management mechanisms	Create good financial eco-system; Keep balance market competition and regulation; Provide tax deduction for the capital invested in the high-tech enterprises
Central government	Economic and social development; National security	Demand and needs of the people; Global competitive pressure	Improve the infrastructure, especially those related to ICT, to facilitate the transmission and flow of knowledge; develop effective market; Strengthen the social security system; Increase investment in education and enhance the quality of education; Improve national innovation system; Sustained 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 rule-of-law Government; Responsive to the people's demand
Local government	Sustainable regional economic and social development	Performance appraisal by superior; Competition between regions; demand and needs of local citizens	Improve infrastructure and institutions to create an enabling environment for business start-ups and innovation; Promote R&D by firms; Promote the development of local industrial clusters	Reform appraisal system for local government officials Promote regional competition in a unified national market; Responsive to the people's demand

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