China's Transition to the Innovation-Driven Economy: Stepping Stones and Road-Blocks

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Abstract: - Besides its past outstanding accomplishments in terms of extensive development, China has also accumulated multiple distortions and structural imbalances and has reached a crossroads, where a major qualitative switch is a must. Its outdated export-oriented economic model has covered both the factor-driven and investment-driven stages of development and now China needs to more firmly advance towards the stage of innovation-led growth, transiting from cheaply processing and assembling foreign-designed goods, using foreign-designed technologies and supplying foreign markets, to producing high quality, services-and-knowledge-intensive products, using locally-devised technologies and meeting, primarily, its own domestic demand. This paper looks at the progress attained in recent years in the Chinese research, development and innovation system, sketching its landscape in terms of structure, endowment and goals, inputs and output improvement, significant shifts and trends paving the way to an innovation-driven economy, as well as to potential road-blocks on the way.

Keywords: - China, innovation-driven development, innovation-led development, innovation-intensive, R&D, S&T, science and technology, development model

1 Introduction

Recent economic development history provides compelling proof of innovation playing a crucial role in the catching up endeavour of emerging economies and in their successful avoidance of the middle income trap. Absorbing foreign knowledge, adopting and adapting foreign technologies and know-how at early stages of the catching up process when input costs are still low, help foster industrial upgrading, productivity gains and competitive advantages, leading to higher GDP growth and, ultimately, to improved living standards. However, just capitalizing on technology transfers is never enough for any economy, as, later on, when having attained a higher development level and having got closer to the technology frontier, indigenous innovation capacity becomes a must. Therefore, a wise approach to economic development should always see to building a strong local innovation capacity beforehand, way before the moment when foreign technology transfers no longer suffice and the only pathway left available is that of the in-house innovating effort to push further the technology frontier.

China has both the historical background and the potential to become an innovation powerhouse. For much of human history the Middle Kingdom was not only the largest economy in the world, but also the leading science and technology fountainhead. Some of the greatest inventions of mankind, having a major bearing on the world evolution – the earliest known cast metal coins, paper, the first paper money, the first commercial advertising notice, the printing press, the iron plough, the nautical compass, some of the first oceans and sky maps, gun powder, porcelain, silk and many others - were ancient Chinese discoveries. China's economic decline, which started in early1800s, seems to have had structural reasons – according to the historian Mark Elvin's theory – a condition called "the high-level equilibrium trap", when "… the country ran well enough, with cheap labour and efficient administration, that supply and demand could be easily matched in a way that left no incentive to invest in technological improvement" (The Economist, 2015). The 19th century was extremely troubled for China, which was torn by wars, rebellions, natural disasters and famine, lost tens of million people, wealth and territories, its economy plunged and the empire demised at a time when exactly the opposite happened in the Western world, where economies flourished as the industrial revolution unrolled. As it kept lagging behind, China ceased to play a significant role on the global scene, both as an economic power and as a knowledge, or technology provider.

It was only after 1978, when following a bold investment-led and open-to-the-world strategy designed by Deng Xiaoping, that Chinese economy has visibly changed course and managed, in only three decades, an amazing come-back: it achieved large-scale industrialization, urbanization and modernization, growing yearly by an average rate of almost 10% and becoming the second largest economy in the world (2010) behind the USA; it also became the largest global manufacturer (2010), international trader in goods (2012) and foreign reserves holder (2006) and it took dominant positions in various markets, influencing global demand, international prices, trade flows and global economic growth. The country also managed an outstanding poverty alleviation, creating tens of million jobs yearly, pulling out of poverty hundreds of million people (about 500 million according to the World Bank) and improving their living standards and life expectancy (Pencea, Bâlgăr, Bulin, 2015). And although in recent years the growth rate kept declining - getting almost halved to 7.3%, between 2007 and 2014 - according to the IMF, China became the largest economy worldwide by its 2014 GDP at PPP, while the US slipped into the second position for the first time in 142 years (Duncan&Martosko, 2014).

The export-oriented and investment-driven model implemented in China, which turned the country into the "workshop of the world", able to manufacture and deliver almost everything, anywhere, at the lowest price, has performed very well for about thirty years, but it has progressively reached its limits and, in particular after the outbreak of the global economic crisis and the implementation of the stimulus package of 2008-2010, it revealed its negative outcomes: inefficient resource allocation, wastage, structural imbalances, asymmetries, development and income gaps, growing non-performing loans and skyrocketing debt, expanding shadow banking, economic bubbles, corruption, widespread pollution. After 2010, the economy has decelerated, returns on investment kept decreasing, the RMB gradually appreciated, the demographic dividend kept fading away, while wages went up eroding the competitive advantage. Additionally, some of the reforms envisaged by the new leadership, targeting improved allocation by liberalizing interest rates, energy and commodities prices, are expected to have a similar short-term outcome. In other words, against the backdrop of a development model that is turning obsolete, the whole economic environment is profoundly and swiftly changing and, in response, Chinese economy requires an entirely different approach to development.

Through a quantitative and qualitative approach, our paper explores the way in which China is trying to operate this complex change, looking at its challenges, at the steps already taken or planned for the future, at the current accomplishments and potential road blocks.

2 Literature review

In his famous book *The Competitive Advantage of Nations,* Michael Porter (1990) identified four stages of economic development in a nation's evolution: (i) factor-driven, (ii) investment-driven, (iii) innovation-driven and (iv) wealth-driven development. In China's case, the old investment-led and export-oriented development model has covered both the factor-driven and the investment-driven development stages. Therefore, from now on, to help rebalance its economy and ensure sustainable growth, China needs to more firmly advance towards the stage of innovation-led growth. Even if it managed a spectacular economic revival and re-emergence at the top of the world economic rankings building upon manufacturing, ***in terms of knowledge creation, research, development and innovation, China is still a follower, not a leader***, and it still has a long way to go before it becomes an innovation-driven economy and a genuine new technology provider. The signals coming from both the domestic and the external markets express the urgency of its transition towards a new, innovation-driven development model, focussed on quality, productivity, competitiveness, deference to nature and accountability for the ways in which its resources are used and the environment changed. These signals imply that China must foster R&D, promote indigenous innovation, encourage companies to rise productivity and climb up the technology ladder, adding more in-house value to goods and services, so that employees are paid higher wages and, consequently, they consume more and save less (Pencea, Bâlgăr, Bulin, 2015).

The same comes out of a recent study by McKinsey Global Institute (MGI), which concludes that China faces the imperative of innovation which is needed in order "[… *to contribute up to half the Chinese GDP growth by 2025, or about USD 3 trillion to USD 5 trillion in value per year*]" (McKinsey, 2015). Similarly, Zilibotti (2015) considers that introducing policies and institutional reforms that trigger the switch from investment-led, to innovation-driven growth is "[*the crux to escape the middle income trap*]". On the other hand, according to Michael Schuman (2015), "[*It is easier to jump from a very poor country to a middle-income nation, than to advance from that middle-income status to the ranks of the truly developed*]". A poor country can quite easily generate GDP growth, using its cheap labour and other resources in a modern economic system, because low wages attract investment in labour-intensive industries, accelerating growth. These countries catch up quite quickly by encouraging investments and by copying foreign technologies (Zilibotti, 2015), but, as costs rise and basic industries become less competitive, they need to start improving skills and developing their own intellectual property, so that they become more capable to compete in high-technology industries. At this point, those who do not activate their own innovation capabilities risk falling into the middle-income trap, no longer being able to compete in either the low-tech industries, (as they have lost their competitive advantage), or in the high-tech industries (because they have not yet created their own new technologies, skills and know-how to compete with the truly advanced nations). This is the point where China finds itself now.

Historically, in the last half of the century just a few developing countries managed to successfully transit to the group of the highly developed economies, while the bulk of them got stuck "*in the middle*". A 2012 ADB[1] research found out that 35 of the 52 middle-income economies reviewed were trapped (Schuman, 2015). With an average income of USD 7129 per capita, China is quickly approaching this turning point[2] when companies become increasingly unable to further compete in terms of costs and are compelled to focus on innovation and quality improvement, to foster brands and climb the technological ladder. As Schuman underlines, citing an Eichengreen, Park and Shin study, "[…*elements of the China growth story make it vulnerable to the middle income trap*]": its extremely high growth rate when it was a poor country; its high investment to GDP ratio coupled with its decreasing returns on capital; its high and growing old age dependency ratio. He therefore concludes "[… *the way to escape the middle-income trap is to successfully change a nation's growth model*]."

3 Pieces in the Chinese innovation-led growth puzzle

3.1. A dominant top-down approach to the innovation system

The innovation system in China still bears the footprint of its initial model, the Russian one: it is still strongly centralized under the control of a small number of top institutions that establish the goals, design the strategies, the policies, the measures to be taken and their implementation modes, under a top-down approach. The main decision power in these matters belongs to the State Council (the government), through its Leading Group on Science, Technology and Education which makes the most important decisions and coordinates their implementation, while another important governmental body is the National Development and Reform Commission (NDRC), which is in charge with designing short-term (5 years) and long-term (15 years) strategic plans that underpin resource allocation. Then, there are the second-tier institutions, ministries and academies, with the Ministry of Science and Technology (MOST) playing the most important role in relation to policies designed to meet the long-term plans and their implementation, formulating laws and regulations for science and technology (S&T) development and reform. Finally, the third tier is that of the research institutes, universities, laboratories, think tanks and enterprises with RDI activities developed inside or outside science and industrial parks (Bichler & Schmidkonz, 2012).

3.2. Strategic planning for innovation-led selective industrial policy

Until very recently, the fundamental document regarding China's strategy on RDI was the "Outline of Medium and Long Term Plan for National Science and Technology Development, 2006-2020" (MPL), issued by the Chinese government in 2006, with the goal of underpinning China's strategic target of becoming a country that "[…develops, influences and owns the core intellectual rights over the next generation of technologies that will power global economy]". MLP was meant to help strengthen indigenous innovation capabilities so that China could become an innovation-driven country by 2020, and a world leader in science and technology by 2050. It provided for rising R&D investments to 2.0% of GDP by 2010 and to 2.5% by 2020 (Lin, 2013). It was the first official document that spoke of, and stressed on indigenous innovation[3], while

[1] Different studies identify it at either around USD 10 000-11, or around USD 15 000-16 000 per capita, the average income of a country that risks becoming captive in the middle income trap (ADB, 2012).
[2] 2005 PPP dollars.
[3] *Indigenous innovation* was defined as encompassing three different forms (i) *original, genuinely new, independent innovation,* (ii) *integrated innovation*, resulting from combining existing technologies in a new, innovative way, and (iii) *assimilated innovation,* obtained by improving and adapting imported technology.

MOST and NDRC defined, in a later document, the products considered indigenous innovation, by certain attributes.[4] Another important strategic document issued by Chinese authorities in mid-2012 was China's Five Year Plan (FYP) for Strategic Emerging Industries (SEI), which nominated 7 emerging strategic fields that were to benefit primarily from governmental funding[5] and established for these industries the goal of reaching 8% of GDP in 2015, and 15% in 2020 (Reuters, 2012). This specific FYP for high tech industries has not only brought a substantial rise in R&D funding for these sectors, but it also announced a radical change of approach to Chinese-foreign R&D cooperation, by abandoning the previous protectionist stance in favour of encouraging international R&D partnerships and cooperation (Pencea, 2014b). As 2015 is the last year of the 12th FYP 2011-2015, it is expected that a draft of the 13th FYP (2016-2020) will be submitted to the National People's Congress in March 2016, followed in the second half of the year by the industry-specific FYPs, including the new FYP for SEI. According to the announcements by NDRC, China's new FYP (2016-2020) for strategic emerging industries will further boost innovation efforts (Lan, 2015).

However, the most recent and important strategic document already in force is *Made in China 2025*, released in the summer of 2015 and seeking to further guide China's advancement to the status of a country with an innovation-led development. This strategy draws direct inspiration from Germany's "Industry 4.0" plan and envisages a comprehensive upgrade of Chinese industry around the central idea of intelligent manufacturing, which basically means applying information technology (IT) tools to production, connecting SMEs more efficiently into the global value chains (GVCs) and global production networks (PNs), for an efficient customisation of mass production. In its view, this thorough rethinking and reform of manufacturing could help Chinese producers, whose efficiency and quality are highly uneven, to overcome the challenges they are expected to face and avoid being squeezed between the low-cost producers and the high-tech ones (Kennedy, 2015). The new strategy rests on a few guiding principles - making manufacturing innovation-driven, focussing on quality over quantity, optimizing the industrial structure and nurturing human talent – all of which aiming at transforming the Chinese industry so that it occupies the highest links in GVCs. It also establishes the goal of raising the domestic content of core components to 40% by 2020, and 70% by 2025, and, although the plan is to upgrade the industry at large, it, nevertheless, highlights 10 priority sectors.[6]

"Made in China 2025" is considered better conceived and adapted to China's present situation and national interest as compared to MLP and SEI, as (i) it focusses on the entire production process not only on innovation, (ii) it caters to the development of both advanced and traditional industries, as well as to modern services; (iii) it still implies state involvement, but gives greater prominence to market mechanisms and forces; (iv) it includes clear and specific measures for innovation, quality, smart manufacturing and green production, with benchmarks for 2013 and 2015 and goals set for 2020 and 2025.

3.3 The R&D investment rush and its hall-marks

The cornerstone of innovation-driven growth is the R&D activity, as it provides for the knowledge creation that underlies the development of new products, services and technologies. R&D activities require considerable investments on a constant basis, while they are time-consuming activities, with little or no guaranties of success. When they succeed, their short-term impact may be significant, but the big payoff generally comes in the longer-run, provided that the intellectual property is well protected. Given these specificities, companies are reluctant to committing themselves to research and, as such, RDI can develop only in very supportive environments, which enable and nurture both a bold, creative mind-set and risk-taking.

As they are aware of the importance of a robust research sector for successfully switching to an innovation-driven development pattern, Chinese authorities have substantially increased the annual R&D investments, by 12% to 20%, over the past 20 years. Consequently, China became the second largest R&D investor in the world, after the US, with annual amounts totalling about 61% of the American ones. At the current rate, China is expected to better the US by 2022, when each of the two are estimated to reach around USD 600 billion in annual R&D spending (R&D Magazine, 2013).

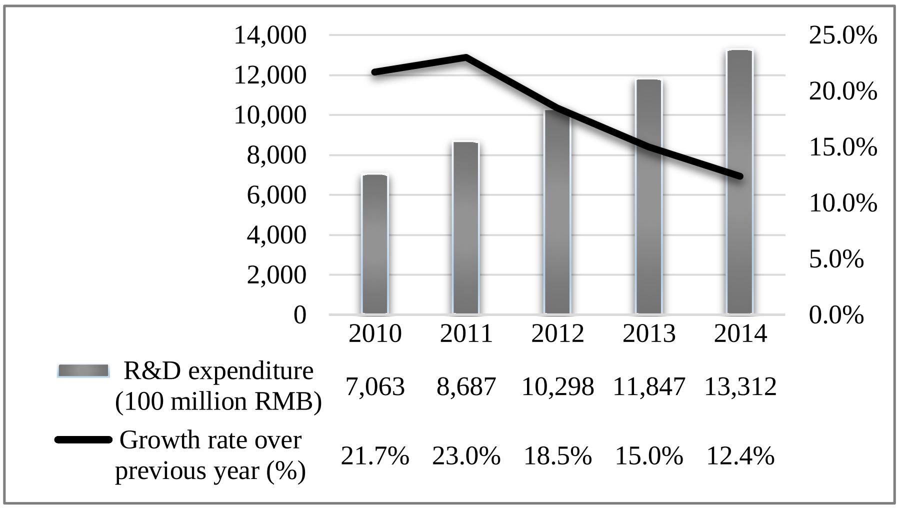
[4] Three attributes distinguished indigenous products: (a) they were developed mainly by domestic companies, (b) the intellectual property rights belonged to domestic owners, and (c) they represented a leap in technology, compared with existing products (Bichler & Schmidkonz, 2012).

[5] New vehicles; energy-saving and environment protection; next generation IT; bio-technology; advanced equipment manufacturing; new energy; new materials.

[6] These sectors are: new advanced IT; automated machine tools & robotics; aerospace and aeronautical equipment; maritime equipment and HT shipping; modern rail transport equipment; new-energy vehicles and equipment; power equipment; agricultural equipment; new materials; biopharmaceuticals and advanced medical products.

According to CNBS[7] (2015), in 2014 the total R&D expenditure in China grew by 12.4%, y-o-y, reaching RMB 1331.2 billion (about USD 217.6 billion[8]) (Fig. 1). Out of this total, the fixed asset investments in scientific research and technical service have increased by 34.5% on a yearly basis, reaching RMB 420.5 billion (about USD 68.7 billion) and accounting for nearly one third of the total.

Fig. 1: Expenditure on R&D activities, 2010-2014



Source: China National Bureau of Statistics (2015).

Against the backdrop of the global economic crisis, with the great majority of countries curtailing their R&D expenditure, China followed firmly its high R&D investment drive, increasing its share of the total global R&D spending, from 10% in 2009 to an estimated 17,5% in 2014 (R&D Magazine, 2013). While the country is still positioned and perceived as a location for cost-effective manufacturing – the high tech production included -, its efforts of developing an advanced research infrastructure and of educating the scientist to operate it, are linked to its goal of evolving from a manufacturing-centred model, to an innovation-based one by 2020.

Chinese R&D investment, accounting already for over 2.0% of the 2014 GDP, goes to both academic research institutions and industrial research firms. But the way funds are split between fields, with only 5% of the total amount for basic research – compared to 15-20% in many OECD countries – and the bulk going to applied and product development research (Van Noorden, 2014) is telling about the pragmatic stance taken by the Chinese regarding the system. Unlike in the US or Europe, in China R&D tends to build on existing products, services and technologies rather than creating new ones, innovating "[…fast enough to keep pace with the moving technology frontier without advancing that frontier themselves]" (Murphree & Breznitz, 2015).

While the central government's plans to promote innovation have been broadly quite unsuccessful, much of the real innovative activity takes place at the local level, where governments have supported entrepreneurship among both private start-ups and foreign investors. As such, a unique and sustainable Chinese innovation system seems to have been born – the "second generation innovation" - embedding specific patterns of local behaviour (risk aversion, preference for proven business models and short-term profit maximization), while successfully keeping up market positions by adapting, re-engineering and improving products and services invented in foreign countries.

A recent research by MGI (2015) - which looks at a database of 20 000 public companies that account for about 30% of GDP and classifies industries as strong in innovation provided they are able to capture more than 12% of the global revenue (which is China's share of the world GDP) - demonstrates that China has already built considerable R&D strength in a number of industries: the customer-focused[9] and the efficiency-

[7] CNBS= China National Bureau of Statistics.
[8] At the end of 2014, the central parity of the RMB against the USD was 6.1190 RMB per dollar (PBoC, 2015).
[9] The cited paper identifies 4 innovation archetypes in China – *customer focused*, *efficiency driven*, *engineering based* and *science based* – and finds out that Chinese companies in the first two groups perform well globally, while the ones included in the other two, still don't.

driven industries. The first category includes industries which innovate mainly to better satisfy customers. Companies in these industries became very good at identifying and responding to specific market requirements and at offering better products, with features similar to the foreign ones, but at considerably lower prices. Relevant examples are the electrical appliances industry (which captures 36% of the global revenue), or the internet services and software (15%). The second category, of the efficiency-driven innovators, includes companies which innovate in order to cut costs, reduce waste, improve productivity, using a variety of approaches (agile manufacturing, modular design, flexible automation, clustering and networking, etc.). This category comprises industries such as solar panels (51%), or the textile industry (20%) (Woetzel & Baily, 2015; Roth, Seong & Woetzel, 2015).

So far, results are quite impressive, and leading innovation indicators show that gaps are quickly bridged and China is approaching parity with the West. If for the past four decades global research investment was dominated by Europe, US and Japan, it is highly probable that in a matter of only a few years China will take the lead. It gained on Japan in 2011 with higher R&D investments and it is estimated that it will do the same with Europe (34 countries) in 2018 and the US in 2022. At the same time, it should be noticed that, of late, China has become aware of the importance of international cooperation in research, pursuing about a third of its advanced research in collaboration with the US, and about a quarter with European research organizations (R&D Magazine, 2013). A brief outline of China's steadily improving international positioning in the global research landscape, as a result of its R&D investments and commitment to attaining technological prowess, is sketched by the data of Table 1.

Table 1: World top 5 countries by their share in total R&D spending, research intensity and gross expenditure on R&D (GERD) 2012-2014

Country	2012			2013			2014 (e.)		
	R&D expenses in total spending (%)	R&D as % of GDP	GERD (PPP)* Billion US$	R&D expenses in total spending (%)	R&D as % of GDP	GERD (PPP)* Billion US$	R&D expenses in total spending (%)	R&D as % of GDP	GERD (PPP)* Billion US$
1. US	32.0	2.8	447	31.4	2.8	450	31.1	2.8	465
2. China	15.3	1.8	232	16.5	1.9	258	17.5	2.0	284
3. Japan	10.5	3.4	160	10.5	3.4	163	10.2	3.4	165
4. Germany	6.1	2.8	92	5.9	2.8	92	5.7	2.9	92
5. South Korea	5.9	3.6	59	5.8	3.6	61	5.6	3.6	63

Source**:** author based on Battelle and R&D Magazine, 2013. Notes:*PPP – purchasing power parity; (e) – estimates.

Nevertheless, while the state is pouring billions into the country's scientific research, improving China's indices and international rankings, most of the companies are still risk-averse and seem unready to seriously invest in research and innovation. While the R&D intensity – the ratio of the R&D budget to the company's total revenue – is, on average, 3.57% for the Japanese firms and 2.93% for the US ones, for the Chinese large and medium-sized companies it is only 0.97%, a level which shows not only a still low commitment to innovation, but also a certain risk of non-survival for the companies with a R&D intensity below 1% (Cai, 2015). There surely are many innovative companies in China, but, unless the bulk of Chinese companies fundamentally change their attitude towards innovation, many of them might face a grim future.

3.4 Human resources for R&D

With a view to nurturing its human capital, the Chinese Government has constantly allocated important amounts to higher education. At present, it allocates 1.5 % of the GDP to tertiary education. By founding colleges, universities, research centres and other academic and R&D institutions, China has developed the robust physical infrastructure necessary to enhance knowledge in different technological and non-technological fields of study. Currently, there are over 2,200 public higher education establishments of various types, from state universities with a large range of specialisations, to small, narrow specialization colleges. The Chinese higher education system also includes around 1,300 private universities, accounting for around 6% of the total annual higher education enrolment.

There are 24 million students in China, accounting for around 2% of the population over 18 years of age. Most of them, over two thirds, study science and engineering. While the annual number of graduates grew from 1.1 million in 2001 to over 7 million by the end of 2014, and the uptrend continues, the number of doctors in science also grew swiftly: currently, Chinese universities deliver over 30,000 doctors of science annually, most of them (70%) in exact sciences and engineering (Roth, Seong &Woetzel, 2015);

Some of the top Chinese universities have already gained worldwide reputation for their outstanding teaching and research facilities, allowing China to sign agreements with almost 40 countries on mutually recognizing diplomas. Among these there are Peking University (PKU) - similar in status and performance to Oxford and Cambridge - and Tsingua University - the most important technical university in China, equivalent of MIT. Remarkably, Peking University (PKU) ranks 1st in China and the 37th among the first 200 universities in the world.

Additionally, owing to its Top 5 academic institutes and universities that have dominated scientific activity for many years – Chinese Academy of Sciences (CAS)[10], University of Science and Technology of China, Tsingua University, Peking University and Shanghai Jiao Tong University –China was recently worldwide recognized as a science superpower, becoming a growing challenger to American scientific and technological primacy (Shapiro, 2012).

Besides enrolling a growing number of students and improving the quality of higher education, China has started to attract talented and skilled human capital from other countries, using suitable incentives.[11] The MLP has drawn concrete directions whereby, within one decade, as many as possible top level foreign scholars, scientists, engineers, entrepreneurs and senior managers from overseas will be attracted to China. Until 2013, this number was estimated at over 2,000 (Song, 2013). Also, as the Chinese scientific diaspora numbers well over 400,000 scientists (Schiermeier, 2014), another important part of the Plan is to bring talents back to China and involve these foreign-trained Chinese professionals in building their native country's vision for the 21st century – that of a knowledge and innovation world leader. Attracted by the prospect of lucrative funding and new career opportunities, about 2, 265 of Chinese academics and scientists have relocated back home since the scheme was established (Bound et. al, 2013).

On the other hand, since 2011, as China has embarked on a more ambitious Five-Year-Plan (FYP 2011-2015)[12], it has focussed more intensively on increasing the number of researchers. Consequently, according to Chinese statistics, in 2014, the number of researchers reached a total of 3,600,000, placing China first in the world in this respect (Song, 2015). A few hundred thousands of these researchers work in the 1,500 research and development centres opened in China by foreign multinationals, taking over and developing foreign know-how. The others work in the about 4,000 research institutes and the 2,200 universities financed by the government, as well as in the numerous local industrial businesses. (Pencea, 2014b).

Besides the graduates of local universities, the Chinese research system also benefits from an increasing number of graduates from the Western universities. The largest number of Chinese students study in the USA (30%) [as compared to the UK (21%), Australia (13%) and Canada (10%)], which has been the number one receiving country for Chinese cross-border students for the last almost 35 years (Chinese Ministry of Education, 2013). The number of Chinese students has grown by nearly 300% over the last 8 years, and as a result they now account for 23% of the total number of foreign students in the USA. In 2013, China was for the fourth year in a row the country which had sent the largest number of students to the American universities - followed by India and South Korea. (Neubauer & Zhang, 2015). Also, remarkably, over 30% of the PhDs obtained in the USA belong to students from China. All these factors have contributed considerably to an enlarged and increasing pool of specialists involved in Chinese R&D, as illustrated by the evolution in (Fig. 2).

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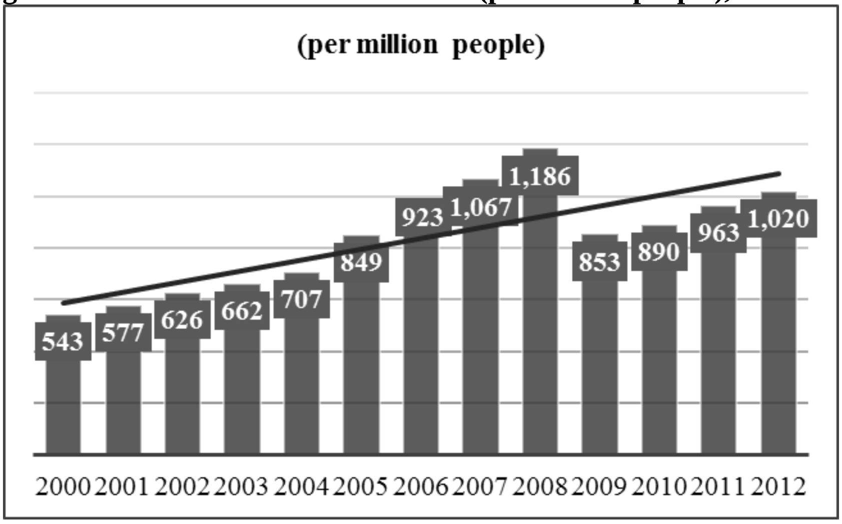
[10] Albeit CAS began as an academy to carry out basic research, it evolved into an academy that endeavoured to strike a balance between basic and applied research over the years (Varaprasad, 2015). Accordingly, at present CAS comprises over 100 research institutes, 12 branch academies, 2 universities and 11 supporting organizations though-out the countries. These institutions host more than 100 national key labs and engineering centres, being located in over 1,000 sites and research stations across the country.

[11] As for instance one of the sub-programs of the "*Recruitment Program of Global Experts*" (*1000 Talent Plan*), the Recruitment Program of Foreign Experts (RPFE), launched in 2008 with the purpose of recruiting non-ethnic Chinese experts, strategic scientists, top experts in science and technology able of advancing the high-tech industries and promoting new scientific disciplines.

[12] The National Development Program for 2011-2015, approved by China's National People's Congress in March 2011, emphasises "*a higher quality growth*" with a special focus on increasing expenditures for R&D to 2.2% of the GDP, by 2015.

Fig. 2: Researchers in in R&D in China (per million people), 2000-2012



Source: World Bank Data (2015), UNESCO Institute for Statistics (2015)[13].

3.5 Scientific output

- **Published scientific works**

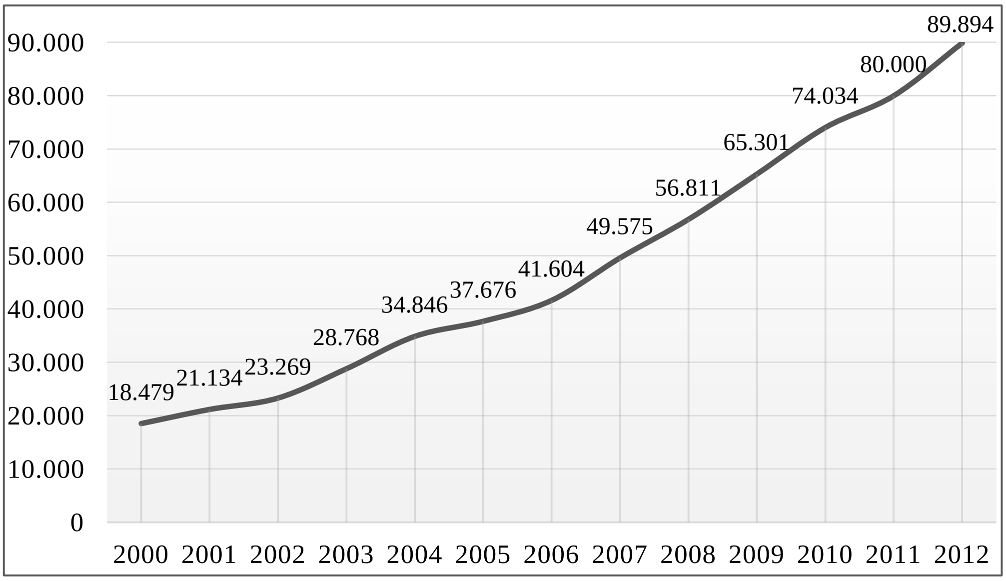
Scanning scientific production, specialists from Thomson Reuters reached to the conclusion that China's achievements surpass from afar those of any other nation (Bound et. al, 2013). Over the last three decades, China has attained the most rapid growth ever seen in the scientific research output of a national research system, achieving a remarkable increase, from around 2,000 to over 150,000 published journal articles[14] per year (2013). The country's scientific production, as assessed from the perspective of peer-reviewed works published after 1981, grew 64 times, with the studies in chemistry and material science accounting for the largest share of the total.

According to Royal Society – the oldest scientific academy of the world in continuous existence – if only 15 years ago the USA was publishing almost 300,000 scientific works on an annual basis, while China was publishing less than 30,000, not before long the USA could be bettered by China in terms of scientific production. As the gap between the two kept closing, in 2008 China was already able to claim the second position behind the United States. Between 2000 and 2012, its scientific output measured by the number of yearly published articles has grown over four times so that, by the end of this time-frame it has already accounted for two thirds that of the United States (Fig.3).

[13] Note: According to the classical definition of the World Bank, researchers in R&D are considered professionals and postgraduate PhD students engaged in the conception/creation of new knowledge, products, processes, methods and systems. The number of researchers also includes the scientists involved in the management of R&D projects (World Bank, 2015).

[14] This number refers only to higher quality "Web of Science" journals.

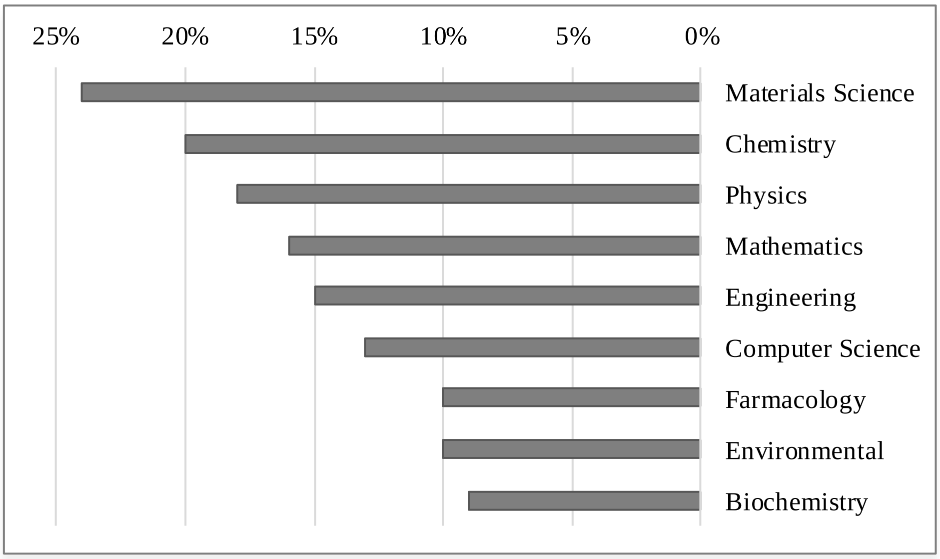
Fig. 3: Scientific and technical journal articles published by Chinese researchers in China, 2000-2012



Source: World Bank Data (2015).

The country's ascendancy in the total world scientific production has also been accompanied by a gradual and significant improvement in quality, quantified by the number of citations per article provided by Thomson Reuter's Web of Science: China has steadily improved the average citation counts over the past two and a half decades, with the ratio between China and the US rising from around 26% in 1990 to almost 60% in 2012. Furthermore, China originates an increasing percentage of global scientific literature, in various cutting edge fields (Fig.4).

Fig. 4: Main fields of China's contribution to the world's scientific literature (%)



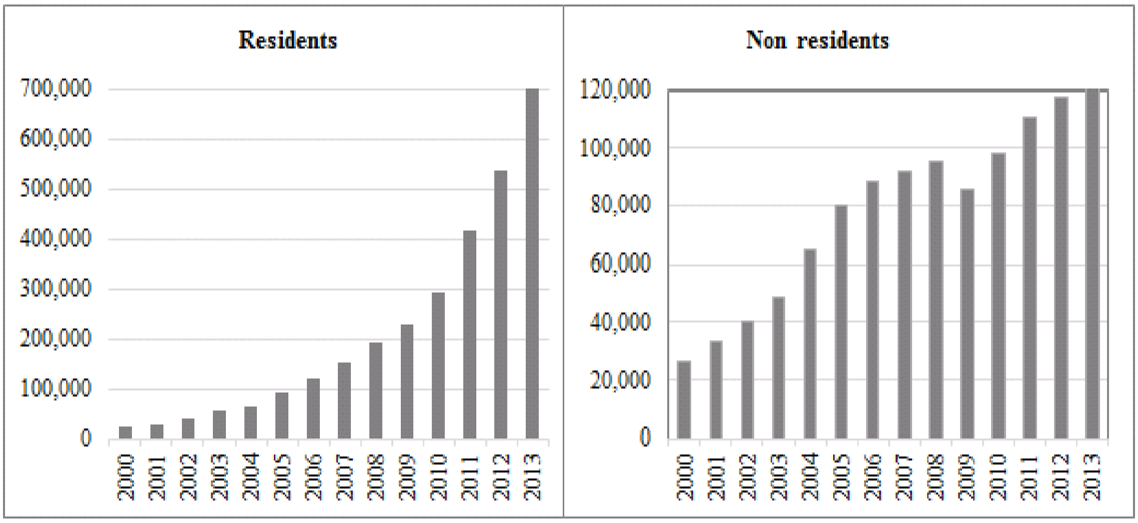
Source: Thomson Reuters Web of Science (2013).

- **Patents**

China is making significant progress in accumulating intellectual capital, measured not only by the number of scientific works and articles published, but also by the total registered patents. Before 2011, in the world hierarchy of countries by number of patents registered at the offices for patents and trademarks, the USA ranked first (with 35% of the total), followed by Japan (27 %), Europe, South Korea and China – geographical areas which cumulated together 75% of all the patents in the world (Grueber, 2011). China has continuously enhanced its number of registered patents and, consequently, in 2012, it held for the first time the top position both as a destination and as a source of patent filing in the world. China residents accounted for almost 561,000 patent applications, much above the next ranked, Japan, with 486,000 applications filed by its residents (WIPO, 2013). In addition, in the same year, the State Intellectual Property Office (SIPO) of China registered the largest number of applications received by any single Intellectual Property (IP) Office: around 653,000 applications, as compared with 543,000 for the United States Patent and Trademark Office (USPTO) and 343,000 for the Japanese Patent Office.

In terms of technological profile, the structure of China's patent portfolio is similar to that of other countries that are large holders of registered patents. Each of the large actors has similar shares in the total of its patents for IT, audio-visual technologies, electric devices, consumer goods, telecommunications, agriculture, chemical engineering, etc. (WIPO, 2013). As for itself, China is focusing on obtaining patents in particular in the following fields (in decreasing order of importance): digital computers, telephony and data transmission systems, radio broadcasting and line transmission systems, natural products, polymers and electro-(non)organic materials. The trend of patent registration applications in China is strongly ascending, in terms of patents submitted both by residents, and non-residents, as also shown in the graphs below (Fig. 5). At the end of 2013, China-registered total number of patents raised to 4.2 million patents in force, of which 3.5 million belonged to residents (83%). Also, a total number of 825,000 patent applications for new inventions were accepted, of which 693,000 belonged to residents (84% of the total) (NBSC, 2014).

Fig. 5: Patent applications (by residents and non-residents) in China, 2000-2013



Source: World Bank Data (2015).

3.6 International commercial exchanges and cooperation

- R&D and international trade

The massive technological transfer to China that has occurred over the last decades from the developed countries – first through trade, then by outsourcing productive activities and, more recently, through relocation and development of R&D activities to Chinese cities – had a major impact on the evolution of the Chinese economy. The productive system has developed and has become structurally diversified, it widened and deepened its range of specialisations, it expanded its geographical scope, creating millions of jobs and business opportunities while companies, both older and newer, learned to cope with competition to gain market share, becoming increasingly better organised, better managed, more productive, efficient and competitive. All these advances became measureable through the export achievements of Chinese companies, both in terms of quantity and, increasingly over the recent years, in terms of quality.

Box. 1: From technology transfers to in-house innovation

a. The case of the high-speed rail industry

One potent strategy China has used to penetrate some HT fields in the global markets of which it subsequently became an important contender, if not the most powerful one, was that of building upon the *technological transfers attracted from the developed economies. The high speed rail transport is one of the most successful such cases of foreign technology absorption, followed by a national innovation effort to improve and push forward that technology. Facts unrolled as it follows: in exchange for a share of China's market, the former Ministry of Railway lured the relevant foreign companies (Bombardier, Kawasaki, Alstom and Siemens) to transfer their technology to their Chinese partners. Afterwards, a huge effort of money, energy and time was put into absorbing, indigenizing the imported technology and, more importantly, developing the core know-how which the foreign companies had refused to share: 25 leading universities, 20 key national laboratories, 40 national institutes and 500 companies were involved in developing the new Chinese high-speed railway technology.*

They succeeded, over last decade, to improve the imported technology and to develop their own intellectual property under Chinese IP rights, so that currently China not only has the largest high-speed railway network in the world (about 60% of the global network, or, in other words, a larger network than all the others in the world put together), but it is also in the position to export this proprietary technology or involve itself in building high-speed railways in other countries.

b. The case of the telecommunications industry

Another successful case is that of the telecommunications industry, where Chinese companies were both forced and helped to develop their own telecommunications standards - including 3G, 4G and 5G - and the specific new equipment. This helped, in some cases, to develop a company culture of permanent investment in new technology and standards. For instance, Huawei normally allocates 10% of its annual revenue for R&D and another 10% for fundamental research. But in 2014 the company invested 14.2% of its revenue for R&D, which accounts for an amount of RMB 40.8 billion (about USD 6.6 billion[15]). Such a philosophy not only has pushed Huawei in leading positions in the global market, but it has also repositioned China from a follower into a creator and provider of new telecommunications standards and technologies. At present, Huawei is the largest supplier of telecommunications gear and derives 70% of its income from outside its home country.

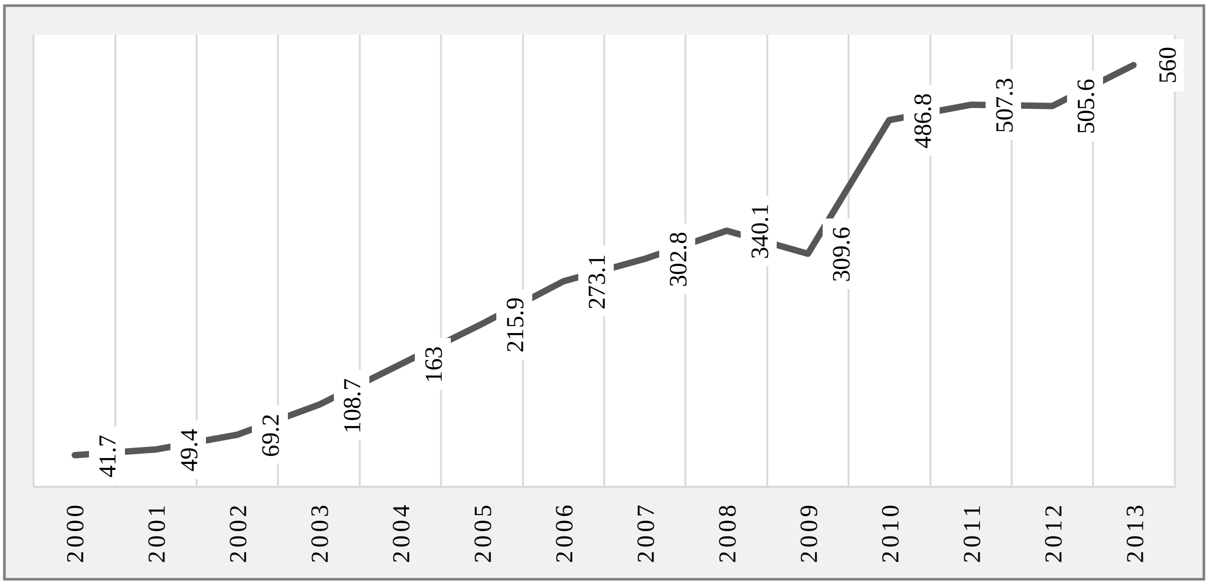
Source: Cai (2015); Rucai (2015).

China is rapidly advancing on the technological ladder changing its position in the global production chains and taking over increasingly superior technologically activities, with higher complexity, knowledge and highly-skilled workforce content. R&D and innovation increasingly become the core and the source of growth and performance in an increasing number of activities, which trigger structural changes in the export supply and an increased share of HT products in the value volume of annual trade.

According to the World Bank Database, in 2013, China reported exports of high-tech and new tech products worth USD 560 billion (almost 10% up, y-o-y), accounting for around 27% of its total export of processed products. These are highly R&D-intensive products, such as those made by the aerospace, computers, pharmaceuticals, scientific instruments and devices, or electrical equipment industries. The graphs below provide an overview of the evolution of these exports as an expression of the increasingly higher contribution of the R&D and innovation activities to industrial performance.

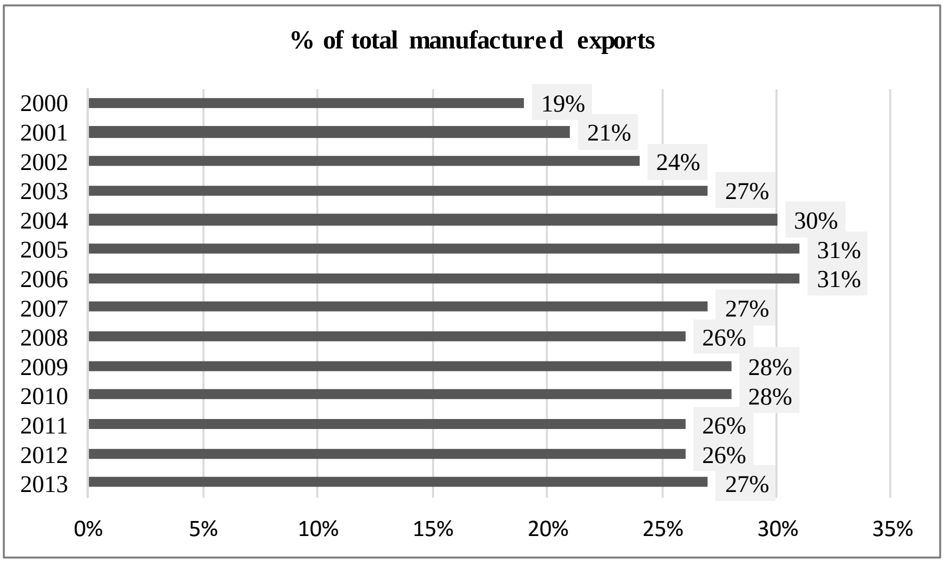
Fig. 6: High-technology exports by China, 2000-2013 (USD billion)

[15] The 2014 estimated average exchange rate: 1 USD= 6.1428 (CIA, The World Factbook, November 2015).



Source: World Bank Data (2015).

Fig.7: High-technology exports by China as percentage of total manufactured exports, 2000-2013



Source: World Bank Data (2015).

3.7 R&D internationalization

Globalization strongly impacts on innovation. Growing R&D infrastructure availability and improved capabilities in more of the world's regions increase the scope and opportunities made available by various forms of international cooperation and interaction, while rising R&D costs and intensified global competition push in the same direction. Innovation is no longer the exclusive prerogative of the economically advanced nations, and countries such as China, which have been successful in their catching up endeavour, have come to possess remarkable R&D capacities and innovation capabilities that recommend them as important potential sources of knowledge creation, as well as attractive locations for R&D investment and desirable partners for international cooperation.

Companies change the way in which they innovate, developing globally extended research and innovation networks and selecting locations and partners by considering the attractiveness of local R&D capabilities, local costs, the domestic and regional markets size, friendly regulation and incentive schemes, if available. Many, if not all of these drivers, exist in China, and that is why, besides its attractiveness as a host country for manufacturing FDI, the country has become in recent years (2007) the most attractive destination for R&D investments (RRA, 2008).

MNCs have played a significant part in China's modernization and global integration, by transferring technology, knowledge, good practices, skills, managerial and organizational know-how, by including Chinese producers in GVCs and helping them adapt to international rigors, vital for successfully facing competition. Of the globally first largest 500 companies ranked yearly by the "Fortune" magazine, over 400 already have one or more research centres in China and the trend is on the rise. The number of research centres set up by foreign MNCs in China has exceeded 1500 units. They favour technology-intensive fields - such as the auto, chemical and pharmacy industries, IT and computers, electronics and telecommunications, software, etc. - on the one hand and, on the other hand, the East or South-East coast cities, especially Beijing, Shanghai and Guangzhou, where the highly-skilled human resource pool is larger.

According to certain analyses, over 50% of the foreign companies established in China have already set up R&D units there (Yan, 2012) and some of the fields they operate in have already shifted from the technological transfer phase to the technological adjusting-to-market-specific phase, and even to the stage of original innovation, as MNCs aim more and more at tapping into the highly creative and yet not capitalized on potential of the local scientists, to create new technologies and products for other markets. Already about 40% of the MNCs which are present in China develop products for other markets than the local one. Over the last ten years, a dynamic shift has happened in what motivates MNCs to set up research units in China. If in the beginning many of them intended to set up some sort of low-cost support for their local operations (cost-drive R&D), they gradually moved to adapting technologies so that the local demand is better met (market-driven R&D) and, more recently, having recognized the country's rise as an innovation power, their motivations started gliding again to tapping into China's science and technology base and into its high-skilled pool of researchers, to pursue fundamental research (Jolly, McKern &Yip, 2015).

Nevertheless, while multinationals obtain higher profits by tapping into the local, comparatively cheaper, but highly qualified, human resources and capitalize on the large local market and economies of scale, Chinese companies have also benefitted significantly from the foreign MNCs presence in their country: it has been estimated that as of 2010, more than half of the technology owned by Chinese firms was obtained from foreign companies (Holmes, McGrattan & Prescott, 2015).

The current trend is that powerful companies from all the countries, China included, will increase their search for foreign locations and R&D partners, as they will rely more on external sources of innovation. Owing to its comparative advantages and local capabilities, China will continue to attract important foreign investment in R&D and strong foreign partners, but it will also seek itself, as part of its "*going out – going global*" policy, to tap into the R&D capabilities of other countries. The recent shift of focus in its outbound direct investments (ODI) from the predominance of natural resources-motivated investments, to investments justified by the access to new technologies, foreign innovative potential and established brand names, unveils just this strategy, which is vital for building an innovation-driven economy back home. There is a growing number of Chinese multinationals searching the world for opportunities, and some of the most searched for opportunities are those relating to research, development and innovation in cutting edge fields, as China needs to come closer to the knowledge frontier and even try to push it further. Developments of the recent few years, with a growing number of Chinese MNCs becoming more visible in the global rankings of innovative companies – as for instance Alibaba, Baidu and Tencent which appear in the top 50 Forbes rankings – or of companies which file an impressive number of patent applications – as for instance ZTE, which ranked first in the world in 2012, from this point of view – as well as the outstanding accomplishments of other companies in aerospace, computing, submersibles, speed rail, green energy and many other fields, provide every reason to believe that China may succeed.

4 Conclusions

At its present development stage, with changed economic fundamentals and accumulated imbalances and asymmetries after decades of frantic export and investment-led development, China is at the cross-roads. The wrong moves could lead it into the "middle-income trap", where many developing economies have been blocked for years, or even decades, while the right strategy, policies and management, which experts believe that should focus on fostering R&D, education and international cooperation in S&T, as building blocks of an innovation-driven economy, could propel China into the group of the highly advanced economies. Accessing this elite is China's declared dream, but "making the leap from the investment-led, to the innovation-driven economy" is a recommendation which comes with almost no details about how to do it, because there is actually little good practice and no recipes on this matter. That is why the road forward will presumably be quite long and difficult, with roadblocks on the way. Some road-blocks come from the price controls which are the root cause of the massive capital misallocation in Chinese economy, hampering the innovative activities of smaller private companies or start-ups. Other road blocks come from the still un-restructured, unaccountable and unsustainable activity of many SOEs, whose preferential treatment and monopoly positions act as a disincentive for innovation. Other challenges may derive from the very structure and geographic pattern of the Chinese innovation system, which, on the one hand, lays too strong an accent on D/development activities, while somehow neglecting R/research itself and, on the other hand, is highly concentrated in just a few big cities, generating a growing innovation gap between regions.

A strong hindrance is also exerted by the poor enforcement of intellectual property rights, which severely discourages creative initiatives and risk-taking. Furthermore, excessive focus on security provision, which limits communication and the spread of ideas, may turn into a road-block on the path to an innovation-driven economy and society, as well as the outdated mind-sets, which are prone to rejecting new ideas. In fact, one may appreciate that, on the whole, the Chinese socio-economic environment is not conducive enough for innovation, lacking flexibility, sufficient freedom and incentives to create, communicate, exchange and refine ideas, cooperate and compete.

Of course many challenges and risks can be thought of, and presumably many others cannot yet be imagined, but the Chinese leadership and society have the inner resources to meet them and seem now prepared to brace to the ride.

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