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Could China Be the Winner of the Next Industrial Revolution?*

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This paper attempts to give a comprehensive picture of China's current position and prospects for growth in the next industrial revolution, assessing whether the country can emerge as one of the "global winners" of the coming transformation. We provide an overview based on a review of the literature on the main driving megatrends of the so-called Fourth Industrial Revolution and present the most important socioeconomic implications affecting China. We progress by analysing China's current economic situation and growth prospects, reviewing secondary data. We find that to ensure a positive grow path, there is a need to enhance productivity via innovation, and we thus evaluate the innovative capacities of Chinese industry. We conclude that China is already a world leader in various industries based on consumer-focused, efficiency-driven innovation, and while Chinese players have not attained global competitiveness yet in engineering and science-based industries, if the country can follow its current path of development in promoting R&D, with no major systemic disturbances, it is only a matter of time before Chinese players will also emerge as world leaders in high-tech sectors.

Journal of Economic Literature (JEL) classification: F18, I23, L16, O00, O30

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1. Introduction

China is at a crossroads, but this time it is not about taking the right or the wrong path, but rather about connecting roads in the coming industrial revolution. We are witnessing the dawn of a new era that will fundamentally change the way we live, work and progress together as a society, and the individuals, communities and nations who are able to embrace this change will be the ones to prosper, as has been the case throughout history. The technological revolution is accompanied by a set of broader socioeconomic, geopolitical and demographic developments, impacting all regions of the world and all aspects of our lives. China is facing the winds of change, passing through a challenging transition from decades of

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unparalleled economic progress and social development to a recent slow-down and weakening prospects of future growth. In this paper, we would like to assess whether China can position itself in this global transformation, building on its unique economic and social characteristics, to come out as one of the winners of the next industrial revolution.

We begin with an overview of the main trends of the next industrial revolution, to demonstrate the gravity and expected impact of the coming transformation. We also present the most important socioeconomic implications of the fourth industrial revolution, with special emphasis on megatrends directly influencing China. We move on to inspecting China's current economic situation and give a short explanation of some of the underlying conditions of the recent economic slowdown, with special emphasis on the declining contribution of multifactor productivity to GDP growth.

Once we have established that – in order to ensure a positive grow path for China – there is a need to enhance productivity via innovation, we progress by inspecting the different sectors of the Chinese economy and evaluating their success in leveraging innovation. We find that many Chinese players in consumer-focused, efficiency-driven innovation-based industries are already world leaders in their respective sectors, while in industries founded on engineering and science-based innovation, the picture is rather mixed. We further our investigation by exploring possible reasons for the lower levels of competitiveness of Chinese companies operating in science and engineering-based industries and by assessing whether China's efforts in research and development (R&D) are up to global standards. We conclude that China is already one of the world's leading powers in terms of R&D expenditure and related institutional support, and if the country can keep following the same path of development, supporting innovation and tackling challenges in the regulatory processes, intellectual property protection and human resource development, the emergence of Chinese firms as world leaders in sectors driven by science and engineering-based innovation is only a matter of time, and its velocity is mostly dependant on the societal uptake of a culture of innovation, provided that there are no major systemic crisis radically affecting the current economic development of the country.

2. What is the next or fourth industrial revolution?

The term 'fourth industrial revolution' became widely known at the Hannover Fair in 2011 (*Eckart 2016*) referring to the *Industry 4.0* or *Industrie 4.0* strategic initiative of the German government as part of the country's *High-Tech Strategy 2020*, to establish itself as an integrated industry leader and market provider. The *Industry 4.0* programme put forward a plan to redesign manufacturing and production processes, which would move from a centralised to a decentralised model, where ICT-based systems and networks could independently exchange information (M2M)[1] to more efficiently manage production processes[2]. As communicated by the European Commission (EC), the term *Fourth Industrial Revolution* refers to technologies and concepts of value chain organisation, as the EC is setting a path to digitise European industry. As stated by the Commissioner for Digital Economy and Society, Guenther Oettinger: "*Digital is transforming European industry. It's changing the way we produce cars or chemicals, and how banks deliver financial services. Our challenge is to turn the Fourth Industrial revolution to our advantage, to reap opportunities it brings,*" (*EC 2016*).

In a broader context, the Industry 4.0 programme also has implications for the competitiveness of the economy and nations at large, as it is based on the goal of maintaining technological leadership in industrial production and R&D (*Eckart 2016*). This broader understanding of Industry 4.0 or the Fourth Industrial Revolution brings us closer to the theme of wide socioeconomic transformation engendered by the digital age, a topic which many world leaders, politicians and industry experts have been referring to in recent years.

Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, argues that "*We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear: the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society,"* (*Schwab 2016*).

The notion of a paradigm shift has also been put forward by economist Jeremy Rifkin, the bestselling author of several books on the impact of scientific and technological changes and lecturer at the University of Pennsylvania. In his most recent book (*Rifkin 2015*), he goes as far as anticipating the emergence of a new economic model "*in the twilight of the capitalist era",* that is *"better suited to organize a society in which more and more goods and services are nearly free*" (*Rifkin 2015:11*). As the title of his book "Zero Marginal Cost Society" suggests, he predicts that due to the advances in technology and the *internet of things (IOT)*, or the *internet of all things*, the communications, transportation and energy industries will change to an extent that will most likely bring down the marginal cost of production to a near zero level in the not-too-far future and trigger a paradigm

[1] Maschine-zu-Maschine or Machine-to-Machine.

[2] Kagermann, H. – Wolf-Dieter, L. (2011): Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, VDI Nachrichten. http://www.vdi-nachrichten.com/Technik-Gesellschaft/Industrie-40-Mit-Internet-Dinge-Weg-4-industriellen-Revolution. Downloaded: 14 August 2016.

shift in our existing socioeconomic models (*Rifkin 2015:18*). The question remains as to which technological advances have the power to change the processes of manufacturing and production with such magnitude that it would have a deep, systemic impact on the economy and society at large.

The term Industrial Revolution was introduced by French economist and political activist Auguste Blanqui in 1837 (*O'Brien et al. 1993*), to highlight some parallels between the economic and social changes arising from the transition to industries with power-driven machinery in the late 18th and early 19th century Britain, and the sudden redistribution of political power in contemporary France. As in France the transition of the political system has been named a "revolution", the changes in Britain, that could be seen as equally fundamental, created an *industrial revolution* (ibid.). The term became widely publicised with the book by British economic historian, Arnold Toynbee, first published in 1884, entitled "The industrial Revolution" (*Toynbee 1884*). Toynbee, however, focused more on the changes in the control of production and the distribution of wealth, rather than the revolutionary nature of the transition itself (ibid.). As John Komlos, Emeritus at the Chair of Economic History at the Ludwig-Maximilians University of Munich, pointed out, the apparent contradiction between the evolutionary nature of economic development and the discontinuity in the growth rate of output per capita during the industrial revolution can be resolved by viewing the industrial revolution not as a structural break, but as an integral part of the economic experience of the previous millennia (*Komlos 1989*).

From the creation of the first mechanical loom in 1784, we can distinguish four waves of industrial revolution. The first industrial revolution at the end of the 18th century was characterised by the use of water and steam power to industrialise mechanical production, the second industrial revolution at the beginning of the 20th century combined the use of electric energy and new production methods, such as the introduction of the conveyor belt to support mass production, while the third industrial revolution automated production through the use of digital technologies and computing power (*Bloem et al. 2014*).

Whether the current transformation can be considered the fourth industrial revolution or simply an acceleration of third industrial revolution and the digital conversion started in the 1960s is still up to debate. Walt Whitman Rostow, American economist and political theorist, was already talking about the concept of the fourth industrial revolution, in the 1980s. In his view, the fourth industrial revolution is characterised by industries based on revolutionary technologies that are just moving from invention to innovation and that share the following four traits[3]:

- They are so encompassing that no one country can dominate them completely.
- They are linked to the areas of the basic sciences that also are undergoing revolutionary changes.
- They are immediately transferable to rapidly industrialising nations.
- They are key to leapfrogging for basic industries.

Klaus Schwab, in his recent book, the *Fourth Industrial Revolution* (*Schwab 2016:3*), argues that indeed we are witnessing a revolution, which "*entails nothing less than a transformation of humankind*" (*Schwab 2016:1*). Schwab bases his assumption on the velocity, breadth and depth and systems impact of the changes, that derive from the combination and interplay of different megatrends (*Schwab 2016:3*). He identifies the drivers of technological change based on three such megatrends: physical, digital and biological (*Schwab 2016:14–21*). The physical manifestations of the technological changes are primarily linked to the debut of autonomous vehicles, 3D printing (additive customised manufacturing), advanced robotics and the use of new materials, such as self-healing and self-cleaning smart-materials, metals with memory or ceramics that convert pressure into energy.

The collection of data using sensors, cloud computing, big data analytics and the application of artificial intelligence and machine learning links the physical side of technological advancements to the digital, making the Internet of Things transformative across all industries. The digital manifestation of the fourth industrial revolution is also the basis for technology-enabled platforms which connect individuals and institutions in new ways, such as blockchain (a digitally distributed ledger mostly known from Bitcoin) and the platforms of the on-demand or sharing economy, such as AirBnb or Uber (ibid.).

The societal effects of these technologies are apparent. As Tom Goodwin wrote in his famous TechCrunch article in 2015: "*Uber, the world's largest taxi company, owns no vehicles. Facebook, the world's most popular media owner, creates no content. Alibaba, the most valuable retailer, has no inventory. And Airbnb, the world's largest accommodation provider, owns no real estate. Something interesting is happening,*" (*Goodwin 2015*). More than just "interesting", the biological megatrends of the fourth industrial revolution are turning into reality innovations that would have seemed plausible only in the realm of science fiction only a couple of decades ago: cheap genetic sequencing and synthetic biology will revolutionise not only the

[3] Rostow, W. W.: The Fourth Industrial Revolution and American Society: Some reflection on the Past for the Future. In: Furino, A. (Ed.): Cooperation and Competition in the Global Economy: Issues and Strategies, Cambridge, Mass.: Ballinger, 1988, pp. 172–181. (*Kozmetsky et al. 2004*)

healthcare and life sciences industry but also agriculture and the production of biofuels (*Schwab 2016:14–21*).

3. Socioeconomic implications of the fourth industrial revolution

The implications of the next industrial revolution for businesses, governments, media, civil society organisations and the people themselves are just as wide-ranging and complex as the breadth and depth and systemic nature of the underlying megatrends. The implications range from practical to ethical considerations, monetary to societal consequences. The fourth industrial revolution could improve the lives of billions of people around the world, but at the same time generate some grave challenges and risks, that must be mitigated in order to ensure inclusive growth.

One of the most apparent effects of the next industrial revolution will be the profound impact of disruptive changes on business models and the employment landscape (*WEF 2016*). We have already experienced major dislocations in labour markets over past decades with production and workplaces shifting to low-cost manufacturing locations in developing countries from more advanced economies[4]. Nowadays, as production is becoming more and more automated through the use of intelligent machines, the advantage related to low-cost human labour supply is declining. This means that a share of jobs is becoming obsolete or is increasingly re-shored to its original location, causing a shift that has a negative effect on labour-intensive-production based economies. As is the case for China as well, the comparative advantage from cheap labour based manufacturing will not serve sustainable development, and moving up the value-chain will become necessary to maintain long-term competitiveness.

According to the "Future of Jobs Report" (*WEF 2016*) of the World Economic Forum, the labour market transformation is expected to result in heightened productivity levels and widening skills gaps, displacing jobs to a considerably larger extent than creating new ones. About two thirds of disrupted job families will be in routine white collar office functions, which raises the need for governments, businesses and individuals to anticipate changes and prepare for the skills requirements of the future. By one estimation, 65 per cent of children entering primary school today will ultimately end up working in completely new job types that don't yet exist (ibid.), which underpins the importance of education systems embracing technological advancements to effectively contribute to social development.

[4] Wladawsky-Berger, I. (2016): Preparing for the Fourth Industrial Revolution. The Wall Street Journal Online. Februar 26. http://blogs.wsj.com/cio/2016/02/26/preparing-for-the-fourth-industrial-revolution. Downloaded: 15 August 2016.

One often cited example regarding the returns to scale and labour intensity of production compares Detroit of 1990 with Silicon Valley of 2014 (*Schwab 2016:10*). About two decades ago, the three biggest companies in Detroit, a traditional industrial centre, had a total market capitalisation of USD 36 billion, revenues of USD 250 billion and 1.2 million workers. In 2014, the three biggest companies in Silicon Valley had a market capitalisation of USD 1.09 trillion, generated roughly the same revenues (USD 247 billion), but with about one tenth of the number of employees (around 137,000).

The changing patterns of manufacturing, as discussed above, will disrupt the labour market, but will subsequently also open up previously unknown opportunities for companies to foster efficiencies and improve product and service offering, which is expected to boost consumption in a more sustainable manner. Companies will be able to enrich customer experience through digital technologies, enhance products via the use of sensors, data analytics and connectivity, bring more collaborative innovations, involve start-ups and research institutes in their design process and invent organisational forms which can better serve and suit a knowledge-based society (*WEF 2016*).

Sustainability is a key theme of the next industrial revolution, since the improvement of energy efficiencies and increasing reliance on green technologies and renewables in production may not only deliver a productivity boost to nations that are heavily reliant on the consumption of fossil fuels, such as China, but may also enhance global resource security and mitigate risks related to climate change. Of course, the creation of a green infrastructure requires high levels of initial investment from governments and companies, but can yield significant returns in terms of direct and also indirect effects.

At a broader level, the fourth industrial revolution and the embeddedness of the internet in all aspects of our lives will most probably enhance and accelerate existing socioeconomic trends, such as the growing level of inequality (*OECD 2011*). More than one half of the world's population has no internet access and almost twenty per cent of the world's population lack access to electricity (Schwab 2016:8). If the diffusion of innovation is not governed adequately, the "digital divide" will continue to widen between nations, communities and individuals, resulting in uneven trajectories of development, especially in countries that already experience significant regional divides, such as China. As stated in an OECD report (*OECD 2007a*), much of the rise in living standards is due to innovation since the First Industrial Revolution, and innovative performance is central to competitiveness and national progress. It still holds true today, maybe more than ever, that the extent to which society can embrace technological innovation will be a major determinant of future progress (*Schwab 2016:8*).

Finally, there are a number of other implications of the fourth industrial revolution, such as the shifting relative power between governments and citizens, questions involving the protection of privacy and information security or the ethical use of artificial intelligence and biological engineering just to mention a few, which are equally significant and would be worthy of investigation, which however cannot form part of this paper, as its primary scope is limited to factors related to sustainable economic development and competitiveness.

4. China at a crossroads

China is entering the turbulent times of this coming industrial revolution after experiencing a long and unparalleled period of economic development in the last thirty years. Since the start of the *Reform & Opening up* programme introduced by the Communist Party in 1978, the country has posted an average yearly GDP growth rate of close ten per cent until recent years, raising the per capita GDP more than 50-fold, from USD 155 in 1978 to USD 7,920 in 2015, lifting 800 million people out of poverty and accounting for more than three quarters of global poverty reduction between 1990 and 2005 (*Eckart 2016*). It is however worth mentioning that this development has been driven mainly by the eastern coastal regions, creating an imbalance with the rural inlands of the country.

As often referred to, the last couple of years have seen a slowing down of the Chinese economic growth, with a declining year-on-year GDP growth rate since 2010, totalling 7.3 per cent in 2014 and 6.9 per cent in 2015 respectively, according to the statistics of the World Bank[5]. Although these numbers are still well above the world average for annual GDP growth (2.6 per cent in 2014 and 2.5 per cent in 2015), they do show a declining trend which may be related to both external factors, as well as to internal structural problems. There has been a decline in the construction industry and manufacturing output, two of the most important drivers of the Chinese economy, but it has been suggested that the contribution of total factor productivity to growth, which has been on the rise since 1978, has become difficult to sustain in recent years (*Xu 2011*). The contribution of multifactor productivity to GDP growth has fallen from nearly 50 per cent between 1990 to 2000, to about 30 per cent in the past five years (*MGI 2015*), hindering GDP growth.

As described by the Solow-model of economic development, the three main drivers of long-term economic growth are population growth or labour, capital accumulation and increases in productivity (*Uppenberg 2009*). Mainly due to China's birth control campaigns and the introduction of the one-child policy, the country's population growth has slowed down notably since the 1970s, gradually affecting

[5] http://data.worldbank.org/.

the size of the labour force, which can no longer drive economic growth. More pressingly, high levels of gross capital formation as a percentage of GDP (almost around 50 per cent) may not be sustainable with the level of total debt having quadrupled from USD 7 trillion in 2007 to USD 28 trillion in 2014, thus amounting to more than 280 per cent of the country's GDP as of today (*Dobbs et al. 2015*). Finally, as China is catching up in technology with the world leaders, it is approaching the innovation frontier, where productivity cannot be further increased by relying exclusively on FDI and technology transfers, and there is a need to generate domestic innovation. There is an imperative to move from an investment-led model to a productivity-based one, to further drive development (*Eckart 2016*).

According to one estimate (*MGI 2015*), in order for China to reach its average annual GDP growth target of 5.5 to 6.5 per cent for the next 5 years, multifactor productivity growth will need to contribute as much as 35 to 50 per cent of total GDP growth, or two to three percentage points per year. Therefore, without labour force expansion and investments to fuel growth, China will have to rely heavily on its innovative capacity to improve productivity. A study led by Jonathan Woetzel (*MGI 2016*), a partner at McKinsey & Co. China, published in June 2016, advocates the case for China to transition to an economic model centred around growth grounded in productivity, to regain economic dynamism and potentially deliver an additional USD 5.6 trillion of GDP expansion by 2030.

According to the study's findings, by seizing five major opportunities to boost productivity, the country could combat slowing growth, deteriorating capital productivity and falling corporate returns, and thus achieve sustained economic progress. The authors of the study warn that delaying the restructuring of the Chinese economy could become expensive, as the ratio of non-performing loans could reach 15 per cent in 2019, from today's official figure of 1.7 per cent. According to their calculations, every year following the current path of development could increase the costs of dealing with bad debts by USD 300 billion to USD 450 billion, potentially causing a substantial slowdown, if not a systemic banking crisis, that could obstruct economic progress.

The five major opportunities for China to move toward a productivity-based economic growth model identified in the study (ibid.) are the following: increasing consumption by better serving middle-class consumers; enabling new business processes through digitisation; moving up the value chain through innovation, especially in R&D-intensive sectors; improving business operations through lean techniques and higher energy efficiency; strengthening competitiveness by deepening global connections, potentially raising productivity.

At least three opportunities of the five identified above are directly related to China's capability to innovate, such as the digitisation of business processes, moving-up the value chain, or increasing efficiency through lean techniques. The remaining two – better serving middle-class consumers and strengthening global competitiveness – also have important indirect connections to improving productivity by deploying knowledge and using new technologies.

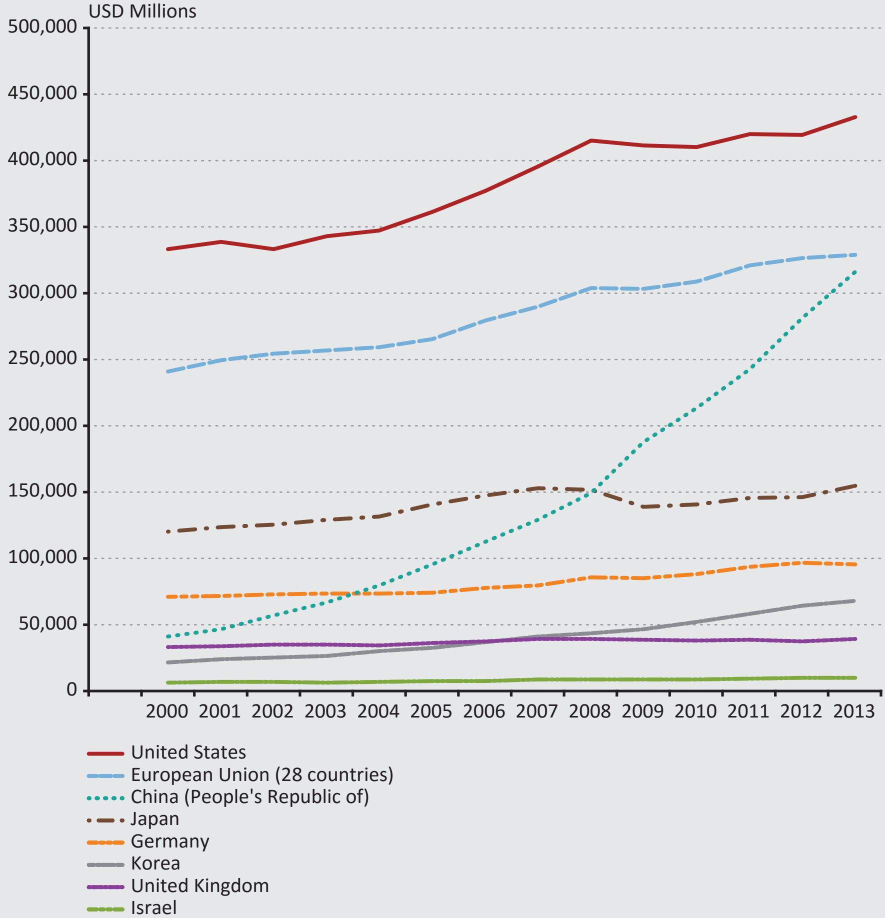
5. The innovative capacity of the Chinese economy

The capability to innovate and to successfully market innovations will be a critical determinant of the competitiveness of nations for the coming decades, as stated by an OECD report (*OECD 2007a*) as well. According to the study, there is a growing awareness among policymakers regarding the impact of innovative activities on long-term economic progress and prosperity. Since advances in new technologies enabled new forms of competition and opened up new markets for the creation and delivery of innovative products, there has been a broad increase in R&D efforts in a number of economies, outside the OECD area as well, and a universal realisation that co-ordinated, coherent, "whole-of-government" approach is required to ensure the central role of innovation in the economy. These trends indicated by the OECD very much coincide with China's ambitions and policies to boost the innovativeness of the economy, but the question remains as to what extent quantifiable indicators of supporting innovation via policies and investments actually translate into measurable impact and tangible results.

China is already a world leader in the promotion of innovation based on numbers. The country has a yearly expenditure of more than USD 300 billion on research, slowly but steadily catching-up behind the United States. It turns out almost 30,000 PhDs in science and engineering per year and leads the world in patent applications with almost a million patents filed in 2014 (*WIPO 2015*). However, Chinese companies commercialising innovations and competing in global markets do not always reflect the potential for success implied by the levels investment and the promotion of R&D in the country.

A 2008 study (*Altenburg et al. 2008*) analysing China's and India's transition from production-based to innovation-based economies sheds light on some of the major difficulties involved in assessing the innovative capabilities of the two countries. The authors claim that indicators of innovative capabilities tend to focus on the input side, and therefore it becomes increasingly difficult to assess whether the gap between effort and achievement is due to the normal maturation time for innovations, or whether it should be explained by inefficiencies in the emerging innovation system. In an attempt to come to an overall judgement, the authors concluded that separate analysis of specific industrial sectors is needed in order to evaluate innovation performance, since analysis based on overall indicators yields poor results (ibid.).

Figure 1
Gross domestic expenditure on R&D
(USD million)

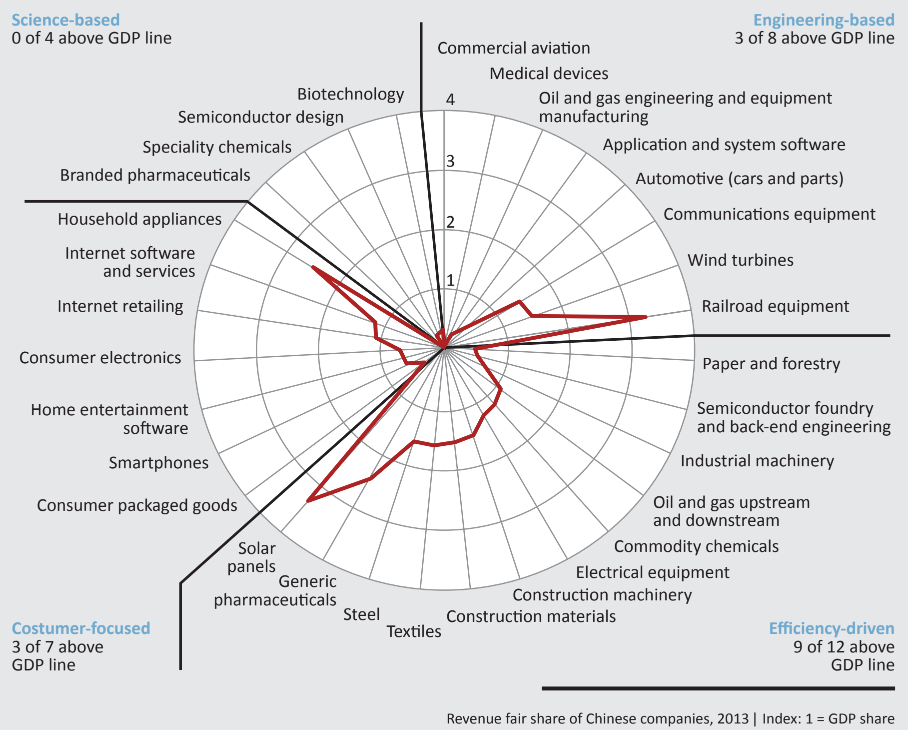


Source: OECD.

In assessing the innovative capabilities of the electronics industry in China, the authors found that China's success in building the world's biggest electronics production hub for global markets is strongly associated with foreign direct investment (FDI), as showcased by the examples of Huawei Technologies, Lenovo, and the Haier Group. Regarding the automotive industry, the other industrial sector investigated in the study, they concluded that although domestic innovation still lags behind that of leading nations, the path of development has been remarkable, as China became the fourth largest producer in the automobile industry worldwide, from having no relevant production capacities only twenty years ago. They also suggest that, with national programmes targeting cutting-edge innovations in fields such as the development of hybrid cars and hydrogen fuel cells, global leaders might increasingly shift their automotive engineering R&D activities to China as an off-shore destination. By examining the industry-specific examples both in China and India, the authors concluded that in all cases reviewed, the two countries have managed to significantly narrow the technological gap, and even though they have not yet seriously challenged global technological leaders, the prospects for catching up remain firm, as long as they manage to mitigate certain economic and political risks (ibid.).

A study conducted last year by the McKinsey Global Institute (MGI) followed a very similar logic in assessing the innovativeness of China's economy. To evaluate innovation performance, the authors developed a framework which analyses industries by their "innovation archetype", rather than using national level metrics, in order to obtain a better understanding on the role and level of innovation by sectors. The four archetypes of industry innovation identified in the study are: *customer-focused, efficiency-driven, engineering-based, and science-based*. To

Figure 2
Ratio of China's share in the global revenue pool to its share of global GDP



Source: MGI 2015, pp. 5.

measure China's success in each of these dimensions, the authors compared the revenue of Chinese players in certain industries in relation to their expected share of global sales, based on China's share of Global GDP (*MGI 2015*).

As revealed by the share of Chinese companies in the global revenue pool, China has become a leading innovator mostly in industries which grew on the basis of serving domestic demand, while in the more challenging types of innovation, such as branded pharmaceuticals, biotechnology or the automotive industry China has yet to become globally competitive. The authors used a multifactor productivity approach in the analysis, inspecting growth that derives from factors of production excluding labour and capital investment, to establish a proxy that would signal the macroeconomic impact of innovation defined broadly, including productivity gains both from pushing the innovation frontier and from knowledge transfers or technological catch-up.

Looking at the overall results of the analysis, it becomes clear that Chinese companies are more successful in archetype industries in which they were able to take advantage of certain characteristics unique to the Chinese economy, such as the size of the customer basis, the extensive manufacturing ecosystem or favourable local government regulations, which helped accelerate innovation by creating local demand. As seen in the figure, Chinese companies are doing particularly well globally in industries based on *customer-focused innovation*, where they have captured more than their expected share of global sales as compared to China's share of global GDP, in three out of seven sectors analysed.

The Chinese experience in customer-focused innovation originates primarily from the appliance manufacturing sector, where Chinese companies started serving the growing consuming middle class of the rapidly urbanising nation, offering white goods at a comparable quality level but considerable price discount compared to global competitors. Continuously meeting consumer expectations has led to the emergence of companies such as Xiaomi, smartphone and electronics producer, following a cheaper but better strategy vis-à-vis global competition (*MGI 2015*). Tapping into the massive consumer base poorly served by the traditional Chinese retail, services and media sector also made it possible for companies such as Tencent, Alibaba, Baidu or NetEase to grow from the grassroots and become some of the world's largest internet companies by market capitalisation[6].

The Internet Plus action plan announced by Premier Li Keqiang in March 2015, at the 12th National People's Congress (*The State Council of The People's Republic of China 2015*), is aimed at further promoting the application of internet technologies

[6] Market capitalization of the biggest internet companies worldwide as of May 2016 (in billion U.S. dollars). http://www.statista.com/statistics/277483/market-value-of-the-largest-internet-companies-worldwide/. Downloaded: 4 September 2016.

in conventional industries, nurturing business development by improving broadband access and e-commerce in rural areas. Overall, high customer expectations and domestic competition in consumer-focused innovation-based industries in China are likely to continue pushing Chinese companies to compete more fiercely at home and to further expand also internationally, utilising their acquired knowledge in the global arena, particularly in emerging markets.

As for *efficiency-driven industries*, the sheer size of the Chinese workforce and the modern supply-chain infrastructure concentrated in industrial zones specialised in flexible manufacturing and mass production provides an unrivalled environment for process innovation. The China effect on global innovation report (*MGI 2015*) finds that, in efficiency-driven industries China achieved more than its GDP-based share of global revenues in 9 out of 12 sectors analysed. The role of government policy interventions is accentuated in some of the sectors analysed, where intentionally boosted local demand has driven supply and subsequently also efficiencies in production. This is the case for the production of solar panels, where China has become such a strong player over the years that it captured more than half of the revenues globally.

With growing competition from South-East Asian nations as off-shoring destinations for cheap-production, China is now projecting the move to the next-generation manufacturing model, by upgrading its existing ecosystem. The *Made in China 2025* initiative, drafted by the Ministry of Industry and Information Technology (MIIT) over two and a half years, with input from 150 experts from the China Academy of Engineering (*Kennedy 2015*), is aimed at comprehensively upgrading Chinese industry, also by fostering collaboration with the German government's 'Industry 4.0' programme (*Yang 2016*). The *Made in China 2025* programme focuses on the transformation of Chinese manufacturing, based on innovation-driven, "quality over quantity" and green technologies production. The goals put forward by the programme include raising the domestic content of core components and materials to 40 per cent by 2020 and 70 per cent by 2025, and supporting the creation of manufacturing innovation centres (15 centres by 2020 and 40 by 2025) (*Kennedy 2015*). The core of the plan is built around developing cutting-edge technologies, accumulating intellectual property and leveraging access to the Chinese market in exchange for foreign technologies (ibid.). Aside from the far reaching technological goals, it also promotes the development of traditional industries and a modern services sector, letting market mechanisms play a more prominent role in its deployment. If China is able to execute its plan to upgrade its manufacturing capacities in a digital ecosystem, serving global customers with a massive supplier base, rapid and flexible manufacturing and modern logistics, it could become the virtual manufacturing powerhouse for companies and even individual consumers around the world, by some estimates expanding its GDP growth potential in manufacturing by 10 to 20 per cent through to 2025 (*MGI 2015*).

While China is already a world leader in several industries based on *consumer-focused* and *efficiency-driven innovation*, so far the country has achieved mixed results in *engineering-* and *science-based innovation* (*MGI 2015*). While China has realised a superior share of global revenues related to its share of the global GDP in businesses such as railroad equipment, wind power and telecommunications (also largely influenced by favourable government policies), in other sectors, such as commercial aviation or the automotive industry, it has not yet benefited from the knowledge transfer in production to the extent to be able to develop globally competitive products and services. In the science-based archetype industries analysed in the report (such as branded pharmaceuticals, biotechnology, semiconductor design and specialty chemicals), the picture is even more consistent, with the total global revenue shares of Chinese companies operating in these sectors ranging only around 1 to 3 per cent (ibid.).

6. Is China ready to create breakthrough innovation?

China's commitment to move to the forefront of global innovation is even more apparent now, as President Xi Jinping has highlighted science-based innovation in the government's 13th Five-Year Plan (*NPCC 2016*), as one of the core points on the national agenda. However, the promotion of science and technology is not a recent direction in Chinese economic development policy. As described by Steve Blank, consultant and guest lecturer on entrepreneurship at U.C. Berkeley and Stanford University, China already started its series of science and technology programmes in five areas (support of basic research, high technology R&D, technology innovation and commercialisation, construction of scientific research infrastructure, and development of human resources in science and technology) in the 1980s. In parallel with the initiative, for the last 25 years, expenditure on R&D as percentage of GDP has almost quadrupled, reaching more than 2 per cent in 2013, according to OECD statistics.

The history of the Chinese National Innovation System is characterised by a tendency of gradual alterations from a largely state-regulated model, to a hybrid, relatively market oriented one. The State Science and Technology Leading Group (STLG) was established in 1981, as the highest body for the direction of the science and technology system in China, as per the modernisation initiative of Deng Xiaoping. By forming a supra-ministerial body, the leadership wished to bring scientific development under the Premier's direct control, where policy would be set at the highest level possible, coordinating between ministries and provinces. The group was later reorganised, under the name State Leading Group of Science and

Technology (SLGST), with Premier Li Peng as its head, building "socialist science and technology" with Chinese characteristics (*Dolla 2015*).

Parallel to the STLG and SLGST, the State Science and Technology Commission (SSTC) was re-established in 1977, after the shut-down during the Cultural Revolution, with the aim of securing a separate (although coordinated) status for scientific research and technological development in the central economic planning. The STC managed the operational network, implementing policy and monitoring activities and resources, at the national and provincial levels. The STC later on transformed into the Ministry of Science and Technology (MOST), the leading organ of Chinese science and technology institutions operating today (ibid.).

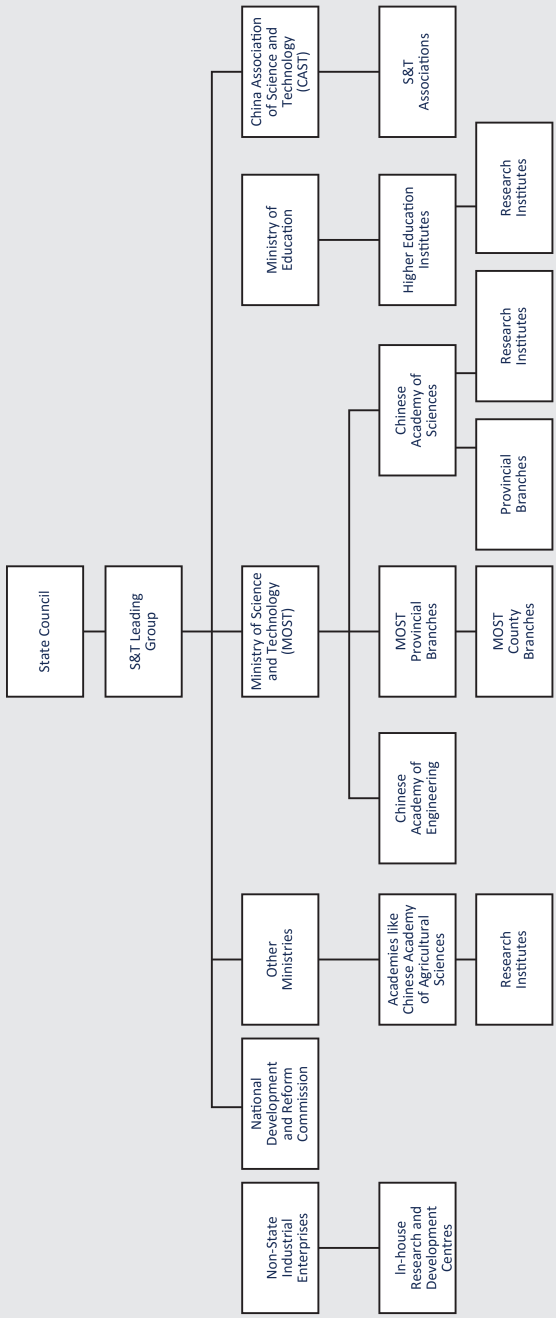
Within the network of organisations, it is worth mentioning two significant entities in the Chinese science and technology landscape: the Chinese Academy of Sciences (CAS), operating research institutes throughout the country, and the China Association of Science and Technology (CAST), a professional association involved mainly in consultation, bringing together scientists and administrators, as an umbrella organisation at the national, provincial prefectural and municipal levels. As for the state funding of research activities, the National Natural Science Foundation (NSFC) is the largest agency for the support of basic and application-oriented research in natural sciences (ibid.).

Along with the transformation of some of the entities in the Chinese National Innovation System, the entire institutional framework has undergone fundamental changes over the last 25 years. The business sector has become the leader in R&D performance, from having a share of less than 40 per cent at the beginning of the 1990s. The share of public research institutes in R&D has declined by almost one half, while the stake of higher-education institutions remained mostly even. Enhancing the innovation capability of the business sector has been a deliberate and challenging undertaking, involving the "mechanical" conversion of public research institutes into business entities (*OECD 2007b*).

Although state influence remains strong, the overall Chinese science and technology landscape today displays a hybrid system, in which government, business enterprises and academia coexist not too differently than they do in other parts of the world. If we look at the sources of R&D funding by sector, based on the data of the UNESCO Institute for Statistics[7], we find that ten years ago about 70 per cent of funding originated from business enterprises, 20 per cent from the government and 10 per cent from universities. Today this ratio is around 75 per cent, 15 per cent and 10 per cent respectively, showing a similar pattern to Western countries and underlining the growing market orientation of R&D activities.

[7] http://data.uis.unesco.org/.

Figure 3
Organisational structure of the Science and Technology system in China



Source: Dolla 2015, pp. 170.

It is now widely accepted that universities and public research institutes have played a pivotal role in the development of many high-tech regions in the world (*Gregersen et al. 2000*), and contributed to the advancement of technological capabilities. It is worth mentioning that most R&D-intensive firms in China have usually emerged from the public research sector, such as Legend, the predecessor of Lenovo, which was established in an institute of the CAS. Today these innovative firms are investing in R&D abroad and are facilitating the technological catch-up process, by channelling knowledge back to China (*OECD 2007b*).

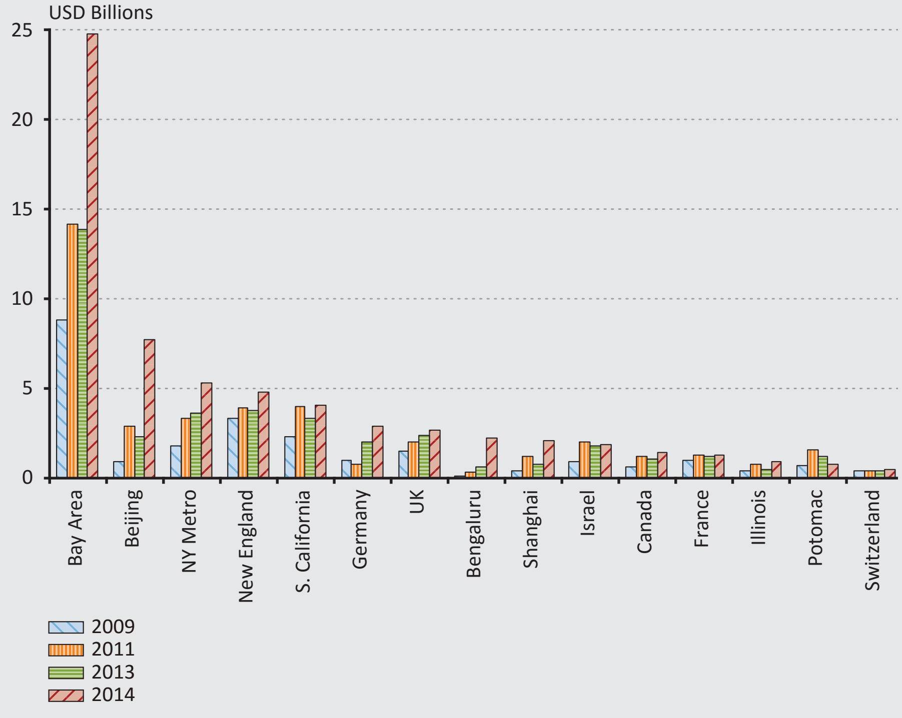
Perhaps one of the most interesting areas in Chinese science and innovation policy is the structured support for small technology-based firms. The majority of these centrally planned science and technology support programmes have been driven by the by Ministry of Science and Technology (MOST) and the National Natural Science Foundation (NSFC). One prime example is the Torch Programme, arguably one of the most successful entrepreneurial programmes in the world, which is managed relatively independently from central planning (*Blank 2013*). The Torch Programme has four pillars: Innovation Clusters, Technology Business Incubators (TBIs), Seed Funding (Innofund) and Venture Guiding Fund, providing a comprehensive support ecosystem for high-tech companies and start-ups, in order to help them develop and bring innovations to the market (ibid.).

As seen also through the Torch Programme, the Chinese state has made substantial investment in the development of science parks and incubators. While many small technology-based firms remain dependent on public support from some level of government, or as tenants of science and technology parks, we can also witness the emergence of purely market-based innovative networks of small firms in some regions such as Zhejiang, Jiangsu and Guangdong, creating a cluster effect (*OECD 2007b*). As reported by the National Bureau of Statistics of China (NBSC) in 2013, the regional cluster effect is highlighted, as the R&D expenditure of industrial enterprises in the top three regions (Jiangsu, Guangdong and Shandong) accounted for more than 40 per cent of the total (*NBSC 2014*).

As Michael Porter described in his epoch-marking article, "Clusters and the New Economics of Competition" (*Porter 1998*), the economic map of the world is dominated by clusters, "critical masses- in one place- of unusual competitive success in particular fields", that "affect competitiveness within countries as well as across national borders". The impact of clusters on competitiveness derives from the fact that, clusters are characterised by their capability to generate breakthrough innovations that can create new industrial domains and redesign value chains (*Ferrary et al. 2009*). Therefore, clusters can be crucial components in the creation and dissemination of innovation in the economy.

As stated by researchers at Stanford University (*Ferrary et al. 2009*), the competitive advantage of an innovative cluster is based on its capability to nurture the founding of start-ups developing breakthrough technologies. Silicon Valley is the most famous innovation cluster in the world, home to the semiconductor, computer software, and related electronics industries (*Citi GPS 2016*), attracting the largest amount of venture capital (VC) investment, having reached almost USD 25 billion in 2014 (ibid.). What is not so widely known is that currently the second largest amount of VC investment goes to the city of Beijing, which has increased its VC investment share from USD 0.9 billion in 2009 to a remarkable USD 7.7 billion in 2014 (ibid.).

Figure 4
VC investment in different regions
(USD billion)



Source: Ernst&Young and Citi Research (Citi GPS 2016:8).

The role of venture capital in supporting smaller technology companies in China is important, since the largely state-owned banking system, mostly provides loans to bigger corporations, especially stated-owned enterprises (SOEs) (*OECD 2007b*). Therefore, the source of financing for small enterprises can either stem from government funds, through the previously mentioned programmes, or from private investors. Further examining the role of venture capital in promoting innovation, researchers at Stanford University found that venture capitalists are a major (and underestimated) source of robustness of the innovation network. The authors applied complex network theory to analyse the innovative capability of the Silicon Valley, viewing the economy as a complex network, defining entrepreneurship and innovation as a result of interactions of numerous economic agents. According to their findings, VC-s contribute to the innovation system not only through financing and selecting start-ups, but also by enhancing collective learning, embedding social ties within the network and signalling levels of risk (*Ferrary et al. 2009*).

Similarly to the case of science and technology support programmes, VC investments have also come a long way in China: in the first wave of start-up funding in the 1990s, 85 per cent of start-up funds of new technology companies in Beijing originated from the research centre or university where they had been created. The second wave of technology investors were Chinese banks, mostly providing financing through the Torch Programme. Science and Technology Industrial Parks were the third source of support for new ventures, also through Torch Technology Business Incubators, licensed by the local governments (*Blank 2013*). Today, there are more than 1,000 Private Equity and Venture Capital firms operating in China, taking advantage of the introduction of the "Renminbi (RMB) funds", that can invest with fewer restrictions regarding industries, less regulatory oversight and better access to listing a portfolio company. RMB funds can be set up both via domestic funds (fully owned by Chinese investors) or foreign-invested funds (partially or fully owned by non-Chinese investors) (ibid.).

According to a report published by Ernst&Young on Chinese venture capital in 2015 (*Ernst&Young 2015*), the top five investors by number of deals carried out were mostly North American firms, completing almost 300 deals during the year. Beside private sector investors, as communicated by Bloomberg magazine, the Chinese government has decided to bolster innovation and reduce dependence on heavy industry by raising more than USD 200 billion in 2015 for government-backed venture funds, an amount unprecedented worldwide. The 780 funds nationwide that receive financing for investment from this amount should help promote the surge in entrepreneurship in the country, according to the government's plans (*Oster et al. 2016*). Although the efficiency and possible negative side effects of this initiative are yet to be experienced, the scale of investment shows a level of commitment from the government, that makes this experiment unique globally.

While the initiative is supposed to spur entrepreneurship throughout the country, the centre of the Chinese start-up ecosystem remains in Zhongguancun in the Haidian District of Beijing. This technological cluster is primarily focused on the Technology, Media and Telecommunications (TMT) segment, with about half of the investment deals going into the internet businesses. The area brings together start-ups and global technology leaders as Nokia, Motorola, Sony Ericsson, Microsoft, IBM, Sun, Oracle or Google, and is located close to some of China's best universities such as the Peking University, Tsinghua University, the University of Science and Technology of Beijing and the Beijing Institute of Technology, creating ideal conditions for innovation to flourish (ibid.). Although there is no exact recipe for creating a truly innovative economy, all of the factors mentioned above, such as the solid institutional framework, attractive research systems, accessible financing and technical support to entrepreneurs and businesses, are some good proxies for describing the density and quality of relationships existing within the innovation system, and they can serve as a starting point to also examine missing competencies that could enhance the overall robustness of the system.

7. Factors delaying the global rise of the Chinese high-tech sector

With about one hundred National High-tech Industrial Zones (*MOST 2010*) and numerous technology specific clusters such as Donghu, Wuhan (optoelectronics), Zhangjiang, Shanghai (integrated circuits and pharmaceuticals), Tianjin (biotech and new energy), Shenzhen (telecommunications) and Zhongshan (medical devices and electronics) (*Blank 2013*) operating in the country with extensive R&D expenditure, accounting for 34 per cent of all corporate R&D expenditure in 2010 (*MOST 2010*), the question remains why China is seemingly lagging behind on engineering and science-based innovation-driven industries, despite all the efforts of both the government and the private sector to develop high-tech industries.

Some researchers (*MGI 2015*) argue that this kind of scientific work simply needs longer times to pay off, since high-tech industries such as pharmaceuticals often require periods of 10 to 20 years of development and testing before launching a product on the market, therefore it is only a matter of time before China's R&D efforts translate into globally competitive innovative output in terms of marketable products and increased revenue streams. Notwithstanding the previous observation, they also find that slow regulatory processes, questions about intellectual property protection and inefficient allocation of government research funds could also play a role as underlying factors, delaying success. Other studies have also identified the central challenges facing China as the strengthening of intellectual property rights protection, along with the construction of innovative cultures and incentive systems, and the development of human resources (*Xie et al. 2008*). Another possible explanation that has been proposed is that the Chinese market is so large that many domestic companies have little incentive to expand abroad, as certain local advantages are difficult to replicate elsewhere, together with the familiarity of the domestic environment (*McKinsey 2012*).

Some authors (*Altenburg et al. 2008*) make an opposing argument, suggesting that the combination of size and fast growth makes a difference in the case of China, and that it will most probably facilitate leapfrog development. According to their explanation, since capital accumulation is possible on a much larger scale, it enables the country to keep investing heavily in R&D, buy embodied technology even in the form of acquiring entire firms and hire leading international scientists and managers on an unprecedented scale. Furthermore, by leveraging its purchasing and political power, China can make deals that give access to its market only in return for access to technology, making it plausible for the country to leapfrog certain steps of the technological development process.

Aside from the time factor, another underlying reason could be that the application of advances in technology, entrepreneurship and innovative approaches – resulting in the creation and delivery of goods and services – is strongly related to the diffusion of knowledge and technology in society, which could be influenced by cultural factors. An OECD study (*OECD 1996*) that explores the network characteristic of the knowledge-based economy has recommended the substitution of the traditional linear model of innovation for a new model centred around the flows and relationships between industry, government and academia that better characterise the development of science and technology in society. Within this system, knowledge distribution power holds crucial importance, and R&D efforts are just the first indicators to map the diffusion of knowledge and innovation in the economy. In this view, investment in R&D is just as important as investment in education, in talent development and in developing managerial skills to successfully utilise innovation.

It has been observed, that the *social technologies* of innovation, embodied in norms and values, organisational forms, incentive systems and public policies, are harder to acquire than the physical ones (*Altenburg et al. 2008*). Studies have examined the role of culture in firms' propensity to innovate, and they found that autonomous, risk-taking, innovative, competitively aggressive and proactive entrepreneurs and firms depend strongly on their cultural foundation. In short, countries with specific cultural tendencies engender a strong orientation to entrepreneurship, hence experiencing more global competitiveness in the long run (*Lee et al. 2000*). Economic reforms and policies of opening up have reshaped the value system in China, but Chinese culture can be described as more collective and with higher uncertainty avoidance compared to Western countries (*Fan 2000*), which suggests that instilling a culture of risk taking and promoting cross-company collaboration could probably enhance Chinese firms' innovative capacity and overall competitiveness (*McKinsey 2012*). Related to social values, beliefs and norms, it is a common misconception that countries operating in a democratic political system, should by definition become more successful economically. In an analysis conducted in 115 countries (*Fagerberg et al. 2007*), the authors found that the character of the political system is not closely correlated with levels of economic development; therefore, there is no evidence to conclude that the insufficient or deferred results of the innovation system of the Chinese economy can be directly related to the nature of the Chinese political system.

Instilling a culture of innovation is strongly related to the build-up of entrepreneurial capabilities and the development of professional and personal networks. It has been observed (*Altenburg et al. 2008*), that strong professional and personal networks that have developed between the new innovative regions in China and India and the old innovative regions in the United States, have helped the mobility of technically skilled entrepreneurs, engineers and scientists, mostly of Indian and Chinese origin. These professionals, with substantial research and work experience in the United States, applied their skills in their country of origin, creating an effect of "brain circulation" between China, India, Korea and Taiwan (ibid.).

The Chinese government has recognised the need to support the build-up of entrepreneurial capabilities and improve the diffusion of innovation by enhancing talent. The government recently launched the *National Medium- and Long-term Talent Development Plan* (*2010–2020*) and the *Thousand Talents Plan* (*Wang 2010*), both aimed at nurturing domestic talent, as well as recruiting talent from abroad, to supply the economy with "rencai", or educated and skilled individuals (ibid.). The development of domestic talent, the inflow of foreign talent, and the stream of "sea turtles", Chinese who have studied or worked abroad returning home (*Blank 2013*), is already slowly changing the Chinese talent pool and will most probably have a transformative effect on Chinese society and economy in terms of entrepreneurial spirit and creative thinking, which may be the missing piece in the puzzle to convert the last bits of R&D ambition into tangible results.

Finally, China's ambition to make its R&D activity "go global" is opening new horizons not only for the country itself, but also for the rest of the world, which is witnessing China emerge as a major source of global foreign investment in R&D operations. Chinese companies have been setting up laboratories and research centres around the globe at a record pace over the past few years, as reported by the Financial Times[8], and announced the opening of nine new overseas R&D centres in 2016 alone, with an estimated capital expenditure over USD 220 million. With research giants such as Huawei expanding their R&D operations abroad, China became the world's largest greenfield foreign direct investor, for the first time overtaking even the United States (*Dettoni 2016*). These efforts to increase innovation capabilities could aid Chinese development not only internally, but also externally, by making

[8] Dettoni, J. (2016): *Chinese R&D goes global*. Financial Times Online. https://www.ft.com/content/ded25056-6f64-11e6-9ac1-1055824ca907. Downloaded: 4 September 2016.

China attractive for multinational corporations as a destination for R&D and other knowledge-intensive services, creating a virtuous circle of technological catch-up (*Altenburg et al. 2008*).

8. Summary

Change is coming, whether we are prepared for it or not, and our ability to embrace this change will be the determinant of whether we will be able to prosper as individuals, communities or nations during the fourth industrial revolution. The new environment created by the coming industrial revolution will fundamentally change our ways of working and co-existing together, bringing along broad socioeconomic, geopolitical and demographic impacts.

China is confronting the arrival of this turbulent era, after passing through a phase of challenging transition, leaving behind three decades of remarkable economic and social development and entering a stage of weakening growth and increased uncertainty. As it is the case with all changes, the next industrial revolution will present challenges to tackle and opportunities to take advantage of, and it seems that China's capacity to diffuse innovation throughout its industry will be a key influencer for the country's path of future development.

Based on our analysis, China is already the world leader in various industry sectors based on consumer-focused and efficiency-driven innovation, while it is still to experience growing competitiveness in the engineering- and science-based sectors. After examining China's commitment to the promotion of R&D and the existing ecosystem that supports technological and innovative firms, we are confident that if the country can follow its current path of economic development, continuously supporting the diffusion of innovation in the economy and instilling a culture of innovation, China could become one of the winners, if not the winner of the next industrial revolution.

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