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Evaluating the conditions for China's 4th Industrial Revolution plan: A neo-Schumpeterian analysis

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by
Chan Hing Lee Henry

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Abstract :

After 33 years (1979-2011) of close to double digit average annual economic growth, the Chinese economy decelerated to a mid-high single digit growth of approximately 7% per year since 2012. The country is currently facing the typical economic transition challenge of moving from being a high-middle income to high income economy. In response to this economic transition, the government launched an industrial innovation program that corresponds to the 4th Industrial Revolution in 2015-*Made in China 2025*, hoping to stabilize and rejuvenate China's growth momentum through innovation. This thesis examines the pre-conditions for the successful implementation of this plan using the three-levels analysis framework of neo-Schumpeterian Economics -micro, meso, and macro.

The thesis examines the rationale of using neo-Schumpeterian Economics in the study, rather than the conventional Solow Model or any of its variants. It also discusses the advantages of using neo-Schumpeterian framework over the New Structural school promoted by prominent Chinese economist, Justin Lin.

At the micro-level, the thesis looks at whether the country possesses the necessary human capital, entrepreneurship, innovation, and execution capabilities to implement the plan. For any new industries to succeed in a country, these factors are the necessary micro-level pre-conditions under neo-Schumpeterian Economics.

The thesis uses various proxies to demonstrate that these factors are available in China for its *Made in China 2025.*

At the meso-level, the thesis uses the technological regime developed in 2000 by neo-Schumpeterian economists, Stefano Breschi, Franco Malerba and Luigi Orsenigo to study China's high speed train industry. The thesis identifies two basic factors behind the success in building China's new high speed rail industry base on the model. Firstly, China has an existing ecosystem with good innovation and absorption capabilities. Secondly, it has a strong, innovative institution that provides critical supports to nascent industries. The thesis builds a model on the technology and market innovation on high speed rail in China at the meso-level. It argues that the model remains valid today and the Chinese government has demonstrated the ability to mobilize the necessary linkages in the model to make it work. The ability to execute industrial policy provides the necessary preconditions for success under meso-level neo-Schumpeterian framework.

At the macro-level, the thesis examines the various government programs in building national capacity at micro-level and building innovative industries under the 4th Industrial Revolution Plan, *Made in China 2025*. The government had demonstrated the ability to play the role of a strong, innovative institution that is critical in the success on the meso-level's new high speed rail industry. Under neo-Schumpeterian Economics, the presence of an "effective" government at micro-level and meso-level is the pre-condition of success at the macro-level.

Based on the analyses, the thesis draws the conclusion that China does possess the necessary pre-conditions to succeed in its transformation journey into an innovation-driven economy under its 4th Industrial Revolution Plan.

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ACKNOWLEDGEMENT

I wish to express my sincere gratitude to Professor John Wong for his intellectual guidance in looking at analysis of industrial development policy using Neo-Schumpeterian Framework of innovation and for sharing his rich experience in the Chinese economy.

I sincerely thank Professor Tan Wee Liang for his diligent review of the thesis and guidance to improve the idea flow in the thesis.

I would also like to thank my wife, Zhao Zhi Yan and my kids, Sherry, Sylvia and Sherwin for their unwavering support to my academic quest.

DEDICATION

Tan Se Hoc & Tai Shui Ha

My deceased parents had always taught me the value of knowledge and lifelong learning. I dedicate this dissertation to them.

Chapter 1 - Introduction:

The speed and scale of China's economic growth is unprecedented in the world economic history.[1] In 1980, China was one of the poorest countries in the world with a real per capita GDP of only 2.5% of the US, slightly behind India's. Since then, China's real per capita GDP has grown by more than 7% annually. As a result, in 2014, it was more than 24% of the US and 130% higher than that of India's[2]. It is the only country that had experienced higher than 7% average real per capita GDP growth of longer than 35 years. Today, the rapid and sustained improvement in average living standard in a country with 18% of the world's population has put China in the position of being the second largest economy in the world in nominal term and the biggest in purchasing power parity (PPP).

The exponential look-alike shape of GDP per capita in current USD from 1980 to 2014 and the annual GDP growth rate in the same period show the success of economic growth at that time.

Fig 1. China's economic development indicators: GDP per capita and GDP growth[3]

[1]Wang, G. (2013). Preface. In Y. Zheng (Ed.), *China: Development and Governance* (p. Viii). Singapore: World Scientific Publishing Pte.
[2] Author's calculation based on Knoema database. Retrieved from www.knoema.com.
[3] The World Bank. (2016). GDP per capita (current US$). Retrieved from http://data.worldbank.org/indicator/NY.GDP.PCAP.CD/countries/CN?page=6&display=default

Reforms define Chinese growth since 1979 and the thesis:

The Chinese economy was running strictly along the Soviet style central planning model since the 1^{st} Five-year plan from 1953 until the reform years of 1979. The country was one of the low-income countries at that time and the government planning system allocates economic resources rather than the market. Under the economic reforms initiated by Deng Xiaoping in late 1970s, the government gradually handles two transitions at the same time: movement from a socialist-planned economy to a market economy, and movement from a low-income developing country up the ladder. The complexity of the transitions always marks the Chinese economic growth, and the unique feature of China's economic growth is that government-initiated policy reforms play a key role in guiding the transition. The experience defied conventional textbook case analyses. One can only understand the Chinese economic development if he or she looks at it from the vantage point of policy reform[4]. The Chinese growth experience demonstrated that planned economy actually has policies that have led to the rapid economic development.

The country moves from low income country to low-middle income country in mid 1990s and high-middle income country in early-mid 2000s. The speedy growth put the country at the threshold of *Middle Income Trap* around the turn of 2010s.

The World Bank. (2016). GDP growth (annual %). Retrieved from http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries/CN?page=6&display=default

[4] Lin, J. (2016, April 29). *Speech on Demystifying the Chinese Economy*. Speech presented at World Bank.

The inevitable economic growth challenge facing a high-middle income country when the rising labour cost renders its traditional growth pillar uncompetitive in the global market place, thus forcing it to move into higher value-added and technologically more sophisticated industries to keep up the growth momentum or get stuck in the Middle Income Trap. The Chinese government has put up an industrial development program- *Made in China 2025,* to meet both the technology challenges posed to its exiting industries by the Fourth Industrial Revolution as well as to overcome the Middle Income Trap[5].

The Chinese economic growth experience had elicited extensive academic interests. Many scholars have argued that the Chinese growth experience contains too much political economic elements and it is not easy to replicate elsewhere[6]. The thesis posits that while China 's growth record is unprecedented and not easy to replicate, the experience is not incomprehensible and can probably be replicated.

The thesis posits that government-initiated economic reform of China is a kind of organizational innovation that facilitates the innovations in the five areas of innovation defined by Joseph Schumpeter. [7] Schumpeterian economics' variant, neo-Schumpeterian economics provides a good tool in the study of innovation economics.

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[5] Wong, J. (2016, April 23). Why China will not fall into the Middle Income Trap. *Strait Times*. Retrieved April 23, 2016, from http://www.straitstimes.com/opinion/why-china-will-not-fall-into-the-middle-income-trap

[6] Naughton, B. (2010, June). China's Distinctive System: Can it be a model for others? *Journal of Contemporary China, 19*(65), 437-460. Retrieved from http://www.eastwestcenter.org/sites/default/files/filemanager/ASDP/TitleVI2013/Naughton.pdf

[7] The five area of innovations are: introduction of new products; introduction of new production methods; opening up of new markets; opening up of new source of materials; new organizational forms in any industry that improve economic outcome.

This thesis looks at the pre-conditions for the successful implementation of *Made in China 2025* using the three levels of neo-Schumpeterian Economics. The thesis posits that any country which can meet the conditions set-up in the three levels of neo-Schumpeterian Economics stands a good chance to succeed in its industrial development efforts and hence, replicates Chinese growth.

The thesis devotes considerable spaces in the introduction section to the Chinese economic reform history and the evolution of economic growth theory. The extensive discussions of the two topics provided the necessary background to support the choice of using neo-Schumpeterian analysis in the context of China's economic development and the *Made in China 2025* plan.

Chinese economy in the reform era -

There are different ways to characterize China's post-reform growth phases. They are not vastly different from each other and here we use the timeline suggested by Zhu[8] before 2012 and that of Wong after 2012[9]. The Chinese reform timeline is linked to entrepreneurship boom as both Zhu and Wong had observed. This validates the Schumpeterian view that innovations and entrepreneurships are closely linked[10].

Agricultural reform, 1978-1984

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[8] Zhu, X. (20120. Understanding China's Growth: Past, Present & Future. *The Journal of Economic Perspectives, 26*(4), 103-124. Retrieved April 9, 2016, from http://www.jstor.org/stable/2329028

[9] Wong, J. (2016). *Zhu Rongji & China's Economic Take-off*. Singapore: World Scientific Publishing Pte.

[10] Entrepreneurs bring innovations to the market to satisfy their personal motives. Hence periods of elevated innovations provide more opportunities for entrepreneurs to emerge.

The country's move from a socialist-planned economy to its current dynamic form started in 1978 when the government adopted a general policy of "reform and opening up", also known as *Gaige Kaifang* in Chinese. There was no systemic design of reform policies. Instead, a consensus within the government was made, in which reform policies must be gradual, experimental and pragmatic. The initial move started in 1978 with the agricultural reform. Farmers were allowed to become contractors of land and were allowed to keep all production in excess of the government quota. The incentives worked so well that the resultant productivity gain in agriculture helped push farmers away from jobs in agriculture, but at the same time maintaining a stable food price. Freeing farmers from agricultural activities and shifting to higher-value secondary and tertiary activities provided the initial boost to the economy in the reform era.[11] Other gradual reforms were implemented in the agricultural sector and by mid-2000s, all agricultural activities were market price-based and all agricultural taxes were abolished.

The shift in employment from agriculture to manufacturing and services in China's economic development can be seen in fig 2 below, where employment in the primary sector (blue line) decreased over time while employment in the secondary and tertiary sectors (orange and grey lines) increased.

[11] This pattern of cheap labour driven initial development model is the famous Lewis model. It explains the growth of a developing economy in terms of labour transition from subsistence rural sector to higher value added secondary and tertiary sector.

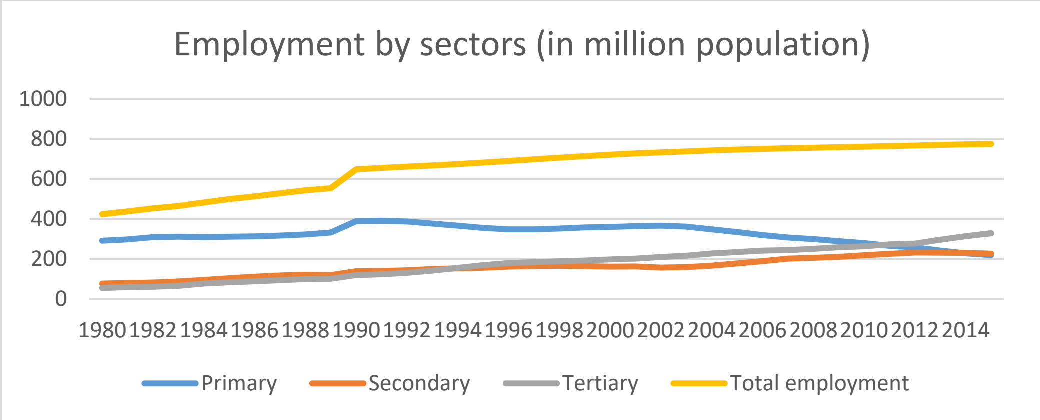

Fig 2. China's employment by sectors (in million population)[12]

Economic reforms and growth:

(1) 1984-1988: Rise of the non-state sector and "Reform without Losers"

The success of agricultural reform can be seen in fig 1. GDP growth between 1981 to 1984 emboldened the government to initiate two market reforms in non-agricultural sectors. First, a dual-track system was introduced into the market. State-owned enterprises (SOEs) were given quotas for both production input and output based on government-set prices, but at the same time, they were also allowed to buy input and output beyond these quotas at market prices. In the dual market, production in excess of the quota ran at market-based pricing while those within quota production ran at government-mandated prices. The incentive to work hard and produce more than one's quota is obvious. Small-scale individual businesses and foreign investment inside special economic zones were also allowed to engage in economic activities specially reserved for SOEs under the socialist system mentioned previously. Second, the central government devolved economic decision-making to local governments and allowed lower-level governments to set

[12] CEIC. Employment by sectors (in million population). Retrieved from https://www.ceicdata.com/en

up rural, collectively-owned cooperatives known as township and village enterprises (TVEs). As a result, provincial-, city-, and county-level governments controlled most of the SOEs, while township and village governments controlled TVEs. The number of TVEs increased from 1.52 million in 1978 to 18.88 million in 1988[13]. This was the first burst of entrepreneurial activity in communist takeover in 1949. Though TVEs were theoretically still owned by the government, they were not subjected to government planning controls.

Preserving the quota-based, low-price socialist system, at the same time providing more goods at a higher market-based price, preserve employment at SOEs and provide employment to excess agricultural workers at TVEs. This is a unique feature of that period and it was called "Reform without Losers".

(2) 1988-1998: From "Reform without Losers" to inevitable trade-offs:

The strategy in the earlier period to allow the non-state sector to grow, without downsizing the state sector, ran its course by the end of the 1980s and early1990s. Increasing losses from SOEs due to market competition forced the government to cut its support on SOEs in the mid-1990s. Many small SOEs and TVEs were allowed to close or privatize through management buyouts, while some large SOEs were converted to corporate organizations. Many of the privatized SOEs or TVEs survived to become the core of Chinese small and medium-size businesses today, particularly in manufacturing. This was the second wave of entrepreneurial activity.

[13] Zhu, X. (2012). Understanding China's Growth: Past, Present & Future. *The Journal of Economic Perspectives,* 26(4), 103-124. Retrieved April 9, 2016, from http://www.jstor.org/stable/2329028

(3) 1998-2007: Encourage private enterprises and trade liberalization

The government legitimized private businesses in late-1997 and the country joined the WTO in 2001. These twin impetuses propelled the Chinese economy into a new phase of growth, as shown in fig 1. The famous BAT (Baidu, Alibaba, Tencent) were all small, private start-ups formed in the immediate years after the legitimization of private businesses in 1998. This was the third wave of entrepreneurial activity with many private start-up going into foreign trade. This period saw the explosion of Chinese foreign trade with increasing private participation.

Fig 3 shows the acceleration of China's foreign trade from 1980 to 2014. It was during this period of time that China became known as the "Factory of the World".

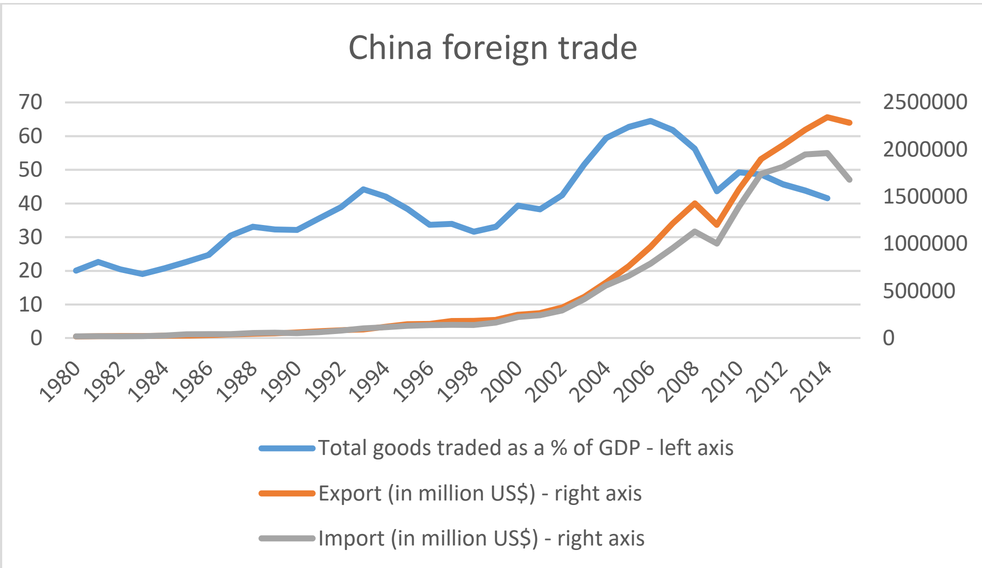

Fig 3. China's foreign trade[14]

(4) 2008-2012: 2008 Global financial crisis and massive government stimulus

[14] CEIC. Foreign trade. Retrieved from https://www.ceicdata.com/en

The government launched a massive RMB 4.0 trillion stimulus program in late 2008, immediately after the 2008 global financial crisis. From 2008 to 2012, while China's nominal GDP accounted for 10-11% of global nominal GDP, the economic growth of China accounted for 30-35% of global economic growth. China was the world's growth engine at that time. The period reinforced China's position as the dominant exporting country and trading country in the world. However, its economy faced an inevitable slowdown from years of hyper-growth and the structural challenges involved in becoming a high-income country, chief among them sharply rising wages (fig 4) and declining productivity[15].

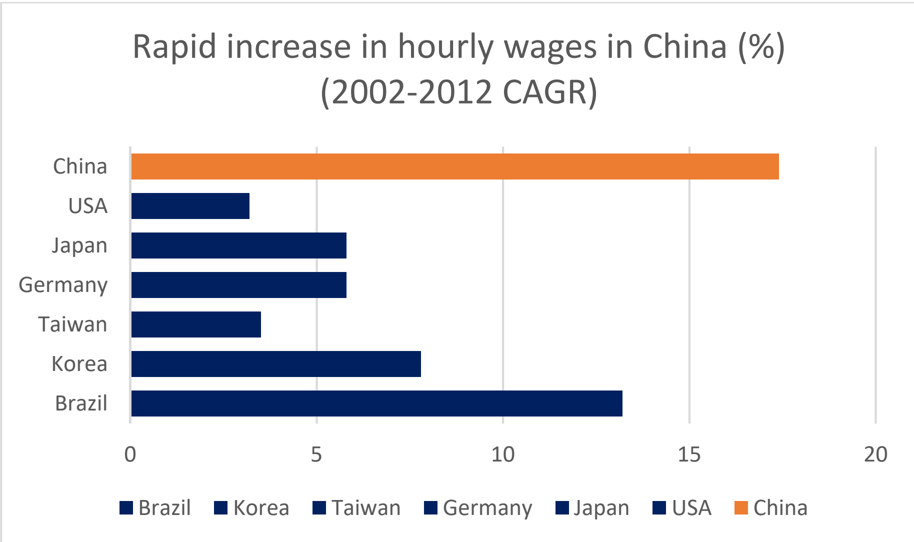

Fig 4. Rapid increase in hourly wages in China[16]

(5) 2013-present: The new normal

[15] Liu, Z. (2015). Is China's Growth Miracle Over? Federal Reserve Bank of San Francisco Economic Letter. Retrieved from http://www.frbsf.org/economic-research/publications/economic-letter/2015/august/china-economic-growth-miracle-slowdown/

[16] Cesar, J. (2016). The Automation Industry in China. *Mirae Asset Lens Issue 7, Part I: Automation in China*. Retrieved from http://www.miraeasset.com/export/sites/com.miraeasset.www/asia/LENS7-Part1/file/Mirae_Asset_LENS_Issue_7_Part_I.pdf

From an average annual growth of 10% between 1979 to 2011, Chinese economic growth dropped to 7.8% in 2012. The earlier favourable growth factors of cheap and abundant labour, cheap capital input fuelled by high domestic savings, and high productivity from technology adoption, have slowly lost their driving power to the economy. In 2013, the government announced the dawning of *The New Normal* in the economy. This brought the economy's lower growth performance to light, and resulted in the change of economic growth drivers from factors accumulation to productivity driven. The key to productivity improvement is innovation and the government called for a transformation of the economic growth model into an innovation-driven one.

The 4th Industrial Revolution Plan - *Made in China 2025:*

China's economic growth has been characterized by punctuated reforms and bursts of growth[17]. The Chinese government is the key pillar in the continuing process of reform, growth and change since the 1978 economic reform. In its drive to reinvigorate the economy, the government promulgated the 4th Industrial Revolution Plan - *Made in China 2025* - in May 2015. Supplemented by a detailed technological development roadmap in a Green Book, the plan sets out broad objectives in the nationwide drive for innovation, manufacturing efficiency, digitization and green development in its original policy paper[18,19]. The Green Book

[17] Lin, J. (2016, April 29). *Speech on Demystifying the Chinese Economy*. Speech presented at World Bank.

[18] China State Council 中国国务院 (2015). *Notice on Made in China 2025 国务院关于印发《中国制造 2025》的通知* (Publication). 中国国务院.

[19] China Strategic Industry Council 国家制造强国建设战略咨询委员会 (2015). Technology Map for Made in China 2025 *《中国制造 2025》重点领域技术路线图* (pp. 1-184, Publication). 北京: 国家制造强国建设战略咨询委员会.

is an industrialization drive covering 10 strategic areas: advanced information technology; advanced computerized numerical control machine tools & robotics; aerospace & aeronautical equipment; maritime equipment and high-tech vessels; modern rail equipment; new energy vehicle and equipment; power equipment; agricultural equipment; new materials; biopharmaceutical and advanced medical devices. *Made in China 2025* declared that the state will emphasize innovation as the driver of economic growth.

Made in China 2025 recognizes that there are two main patterns of innovation in industries. The first one is the *creative destruction* pattern where innovations are introduced by industries that have not innovated enough, resulting in its widening technological distance as compared to its global peers. This is also called 'widening'. The second one is a *creative accumulation* pattern, whereby innovations are introduced by industries that have innovated before and its technological distance from global peer is manageable. This is also called 'deepening'. Based on each industry's technological distance from the global peer, *Made in China 2025* sets specific technological innovation targets for each industry, some 'widening' and some 'deepening'.

China's industrial share was 37% of its GDP and its manufacturing share was more than 30% in 2013. The successful implementation of *Made in China 2025* is critical to China's economic growth and relevant to its catch-up with developed countries.

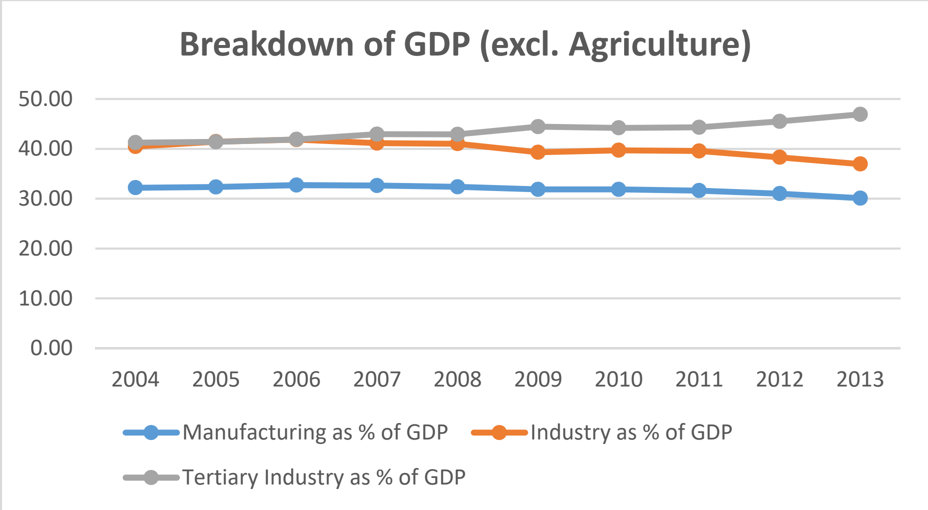

Fig.5 Breakdown of GDP by sector[20]

Empirical evidence shows that all developed countries always build their economy on a few anchor industries. These developed countries are able to continuously innovate to keep their leading industries at the global frontier, and incessant innovation power underpin their success to stay as developed countries. While a successful company easily comes and goes, a globally leading industry has a long term traction. Though the *Made in China 2025* was designed as an industrial development plan, in the case of China, it is actually a national economic reform and growth plan[21][22].

Using neo-Schumpeterian Analysis in lieu of Solow Growth Model in the study

Economists from Adam Smith and David Ricardo to John Maynard Keynes and Joseph Schumpeter have sought to identify the factors behind the long-term

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[20] CEIC. Foreign trade. Retrieved from https://www.ceicdata.com/en

[21] Developing countries economic plan are supply side driven and they are essentially industrial development plan. This is in contrary to developed countries economic plan which are mostly demand side plan. Interested party can read the paper of John Wong in footnote 22.

[22] Wong, J. (2016, June 7). China's macroeconomic conundrum. *The Strait Times*. Retrieved September 6, 2016, from http://www.straitstimes.com/opinion/chinas-macroeconomic-conundrum

economic growth of countries. The study of a country's economic growth is one of the key areas in macroeconomics. Our analytical shift from the conventional Solow model to the neo-Schumpeterian approach can best be explained by revisiting the earlier models of economic development since Adam Smith, and by studying China's current economic transition challenge and policy of promoting innovation as its economic growth driver. Here, we will provide the necessary background information, and discuss why the neo-Schumpeter model is more applicable than the neo-Classical Solow model to address our research question.

A. The classical theory of economic growth:

Classical economists such as Adam Smith, David Ricardo and Thomas Malthus anchored their economic ideas in the Malthusian population principle, the law of diminishing returns, and the theory of subsistence wages. They believed that a healthy, "normal" economic system is in a stationary state - that there is perfect competitive equilibrium with declining profits and no involuntary unemployment, and that the central problem of the economy was how to maintain an economic system's balance and stasis through interacting economic forces. They believed in the concept of laissez faire and advocated minimum government intervention in the economy—Adam Smith's "invisible hand". They maintained that individual initiatives or Smith's "self-interest", if applied in competitive ways to promote personal ends, would serve the general interest in the properly functioning market system. This is further reinforced by Say's Law of the Market ("supply creates demand"), which advocates that automatic adjustments in a capitalist market economy would ultimately ensure adequate demand for goods at full employment.

Classical economists thus believed that a properly functioning market economy would stimulate economic efficiency and growth. They further maintained that a stream of productive inventions would stimulate growth by postponing the emergence of the stationary state[23].

B. Keynesian theory on economic growth:

The Great Depression in the 1930s weakened the central argument of classical economists in their assumption of full employment and the related automatic market adjustment to equilibrium under the capitalist system. To restore economic order, Keynes proposed using state intervention.

Keynes turned away from classical economists' emphasis on the supply side to the demand side, putting the aggregate demand function at the centre of his analysis. He argued that the central problem of the Great Depression was the lack of "effective demand", and that the solution to any economic recession caused by the same problem should be to increase aggregate demand through a direct increase in government expenditure or government policies, so as to stimulate private consumption and investment. In his view, demand creates supply and not the other way around. He recommended the combination of an expansionary fiscal policy along with an accommodating monetary policy to deal with the recession, and that a single injection of government spending is insufficient. Rather, a full scale and long term public spending programme is necessary to deal effectively with the deep recession.

Keynes had not systematically analysed economic growth. However, his government-centric policy recommendations became the basis of Keynesian development planning that was popular from the post-war years up until the 1960s[24].

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[23] Bhattacharya, D. (1989). *Economic Development & Underdevelopment*. Sydney, Australia: Australian Professional Publications. pp24-25

[24] Kuhihara, K. K. (1965). *The Keynesian theory of Economic Development*. London: George Allen & Unwin. p19

More importantly, his national income analysis laid the foundation for the emergence of macroeconomics, focusing on the technical relationship of such aggregates as savings, consumption, investment, and employment. It also led to the popularity of development planning in the post-war years.

C. Modern Growth Theory- the Harrod-Domar model

The modern growth theory originated from the work of Harrod in 1939, and subsequently revised by Domar in 1946. This theory spun off from Keynes view on investment stimulus, and maintained that investment, savings and incremental capital-output ratio (ICOR) are important factors in economic development.

Under the Harrod-Domar model, the economy's "actual rate of growth" has to be equal to its "warranted rate of growth". For this, the first step for economic policy makers is to come up with the right ICOR as well as the desired levels of investment and savings that would result in the target growth rate. In the long run, the economy will grow in accordance with its "natural rate of growth" that is basically determined by population growth. Interestingly, this model approaches growth from the supply side of classical economies, instead of the demand side of Keynesian economics.

One of the biggest problem with the Harrod-Domar model is that it does not provide a mechanism of adjustment for the natural rate of growth in the economy. The natural rate of growth is defined not just as "the maximum rate of growth allowed by the increase of population", but also the "accumulation of capital, technological improvement and the work/leisure preference schedule, supposing that there is always full employment in some sense"[25]. In modern jargon, it does not provide for productivity growth based on technological improvement.

D. Neo-Classical Solow Growth Model:

The Solow model has been the mainstream growth theory since its proposal by Robert Solow in 1956. It is based on the Harrod-Domar model. Under the Harrod-Domar growth theory, it is extremely difficult for the economy to reach the equilibrium rate of growth (or its "actual growth rate" coinciding with its "warranted growth rate") because its key variables from savings to investment and from capital-output ratio to technological progress are perpetually subject to changes. Thus, the "Harrod-Domar economy" was always faced with a very narrow path for its equilibrium growth — the so-called "knife-edge equilibrium". Because of this, Robert Solow proceeded to extend the Harrod-Domar growth theory to include more explanations for equilibrium[26].

The standard Solow model is represented by the equation Y= F (A, L, K). Y stands for GDP output, A stands for technology or production efficiency, L stands for labour input, and K stands for capital input. Under the assumption that technological change is disembodied and factor-neutral, the revised equation will be Y= A F (L, K). However, by refining the key variables of investment, saving and technological progress, numerous growth theories can also be spawned from the Solow model. The key takeaway is that the economy is more likely to achieve its warranted rate of growth if it is more flexible in adjusting the key variables.

[25] Harrod, R. F. (1939). An Essay in Dynamic Theory. *Economic Journal*, *49*(March), 14-33.
[26]For further discussion of this topic, see Higgins, Benjamin: *Economic Development: Principles, Problems and Policies (London, Constable and Company Ltd.1968).*

In the Solow model, a nation's income depends on two major factors of production. These are capital and labour, with time allowing for technological change deemed as the exogenous variable. In the model, capital and labour are perfectly substitutable and factors of production are paid according to the value of their marginal products.

Employing quantitative techniques, neo-classical economists are able to analyse the contributions of capital and labour inputs to national income growth. The famous growth equation Solow model is as follows:

$$\frac{1}{Y} \times \frac{dY}{dt} = \frac{1}{A} \times \frac{dA}{dt} + \alpha \times \frac{1}{L} \times \frac{dL}{dt} + \beta \times \frac{1}{K} \times \frac{dK}{dt}$$

$$\frac{1}{A} \times \frac{dA}{dt} = \frac{1}{Y} \times \frac{dY}{dt} - \alpha \times \frac{1}{L} \times \frac{dL}{dt} - \beta \times \frac{1}{K} \times \frac{dK}{dt}$$

where $\alpha = \frac{L}{Y} * \frac{\partial Y}{\partial L}$ (i.e. output elasticity of labour) and $\beta = \frac{K}{Y} * \frac{\partial Y}{\partial K}$ (i.e. output elasticity of capital).

The residual term called total factor productivity (TFP) is used to explain the growth in output that cannot be explained by growth in capital and labour. In the neo-classical view, total factor productivity is largely associated with technological progress and knowledge advancement.

It can thus be seen that the standard Solow growth model is an extension of the classical approach to economic growth. For this, it has been dubbed the neo-classical growth model. All these models emphasize on capital, labour and technological progress. However, human capital, entrepreneurship or human resource development, is still missing.

There are three ways to measure TFP[27].

The first way is to treat it as a measure of quantities of output per unit of aggregate input. The latter is calculated as a weighted average of all inputs. The weights are either the factor shares in output or the estimated output elasticities of corresponding input factors. In the case of the US, economists assume competitive equilibrium and profit maximization so that the elasticities are equal to the corresponding factor shares in output, i.e. the value of α is 0.7 and β is 0.3 (based on the famous but exceedingly simple Cobb-Douglas production function).

The second way to measure TFP is through the estimation of a production function, which shows how output is related to a combinations of inputs. This method is used in China as the economy is not under perfect competition and profit maximization cannot be assumed. Hence, the corresponding factor shares in output cannot be assumed to take on the production function's elasticities value. Economists obtain estimates of output elasticities of labour and capital by fitting a production function such as Cobb-Douglas's with data:

$Y = AL^{\alpha}K^{\beta}$ and in $Y = a + \gamma T + \alpha \ln L + \beta \ln K + u$.

Wherein ln is the natural logarithm, a, γ, α, β are parameters to be estimated, and u is the random error.

Since A, the productivity indicator, is approximated by a time trend, T, the estimate of γ shows the percentage of output growth that is attributed to the TFP growth. With so many estimators in the equation, it is common to see a wide range of TFP estimates from different studies. The heated debate which erupted in

[27] Liu, Z. (2002). The Nature and Sources of Economic Growth in China: Is There TFP Growth? In *China's Economy into the New Century* (pp. 43-62). Singapore: World Scientific Publishing Pte. Ltd.

Singapore's academic circle in the late 1990s reflects the measurement issue of TFP in East Asian economies[28].

The third way to measure TFP involves the estimation of the so-called production frontier. The frontier represents the best practice. In this context, TFP can grow from two sources. The first is efficiency gain, which is due to the narrowing of the gap between the current production position and the frontier. The second is the outward shift of the frontier itself, which is due to technological improvements over time. This method is difficult to apply and not commonly used.

The absence of human capital in the standard Solow model gave rise to the endogenous growth theory, which Romer and Lucas from University of Chicago developed in the 1980s. This growth theory, $Y(t) = A(t)L(-yt)$, essentially has only one input and one output and assumes that all productivity growth emanates from invention and creativity. Under this extreme Chicago argument, consumption and savings play are not addressed, and everything is human capital or human resource.

Endogenous growth theory has since become the standard tool in the study of economic growth. It posits that growth is endogenous and is the result of deliberate, rational and optimal decisions by economic agents. Aside from labour and capital, new variables such as human capital are also incorporated into the production function. However, the endogenous growth model suffers from the same shortcomings as the original Solow model. It cannot explain what makes up the

[28] Liu, Z. (2002). The Nature and Sources of Economic Growth in China: Is There TFP Growth? In *China's Economy into the New Century* (pp. 43-62). Singapore: World Scientific Publishing Pte. Ltd.

residual term. As economist Moses Abramovitz said, "TFP is a measure of our ignorance". It is convenient to use the original Solow model or its variant to examine ex-post economic performance as data on capital and labour are readily available. However, it is not easy to get an accurate TFP as elasticities data are all based on estimates. The ignorance of what makes up TFP deprives the model of policy recommendation power for the economy on an ex-ante basis, and the Solow model failed to answer these question: What are the sources of its productivity growth? What are the potential sources of productivity gains in the future?[29]

The most widely used method in productivity measurement is labour productivity. It is the ratio of output to labour input, whereby labour input is measured in terms of number of workers or man-hours[30]. Labour productivity's popularity arises from its simplicity and relative accuracy as compared to many sources of errors that we noted in the TFP index construction.

E. Neo-Schumpeterian growth economics

In contrast to the main stream Solow Model, its variant, the Endogenous Growth Model, treats economic growth as an additional economic output generated by additional input of labour, capital, or increased human capital modulated by TFP. Schumpeter considered modern economic growth to be productivity-driven as opposed to earlier pre-industrial revolution economic growth which is factor-accumulation driven. He believed that innovation and entrepreneurship drive productivity gain in the economy. The figure below shows that economic growth –

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[29] Yu, T. (1995). *Adaptive Response: Entrepreneurship and Economic Development in Hongkong* (Unpublished doctoral dissertation). University of New South Wales.

[30] The Japanese economists take issue with this approach, as the Japanese workers are used to long working hours, often mixing work with leisure and other social activity. Japan and other Asian countries thus tend to measure labour productivity on a yearly basis

represented by the circular flow on the left – is triggered by the innovation input of the entrepreneurs that comes from their adoption of new ideas/products.

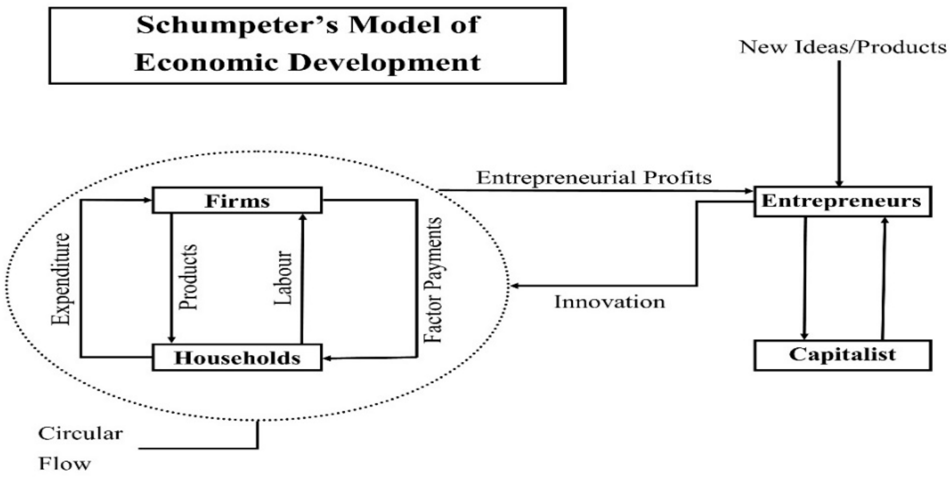

Fig 6. Schumpeterian model of economic growth[31]

Schumpeter's view on economic development was not popular during his time. However, it gained popularity in the last three decades when new high-tech industry was the key economic development driver. Popular terms from Schumpeterian Economics such as creative destruction, productivity, innovation and entrepreneurship have become buzzwords in business school and government policy circles.

Schumpeter's view on economics is different from that of Classical and Keynesian economists because he sees the modern economy as being in a dynamic disequilibrium state which is always growing and changing. Hence, his economic growth is about unstable growth. For him, the study of structural change caused by

[31] Mitra, S. (2013). Schumpeterian Model of Economic Growth. Retrieved from http://www.slideshare.net/satyakimitra/schumpeterian-model-of-economic-growth. Modified by the author on April 24, 2016.

the innovations of entrepreneurs is the main problem of economics. He defines innovation as:

- The introduction of new products;
- The introduction of new methods of production;
- The opening up of new markets;
- The opening up of new sources of raw material;
- New organization forms in any industry that improves economic outcome.

Innovation is the core principle underlying Schumpeterian Economics, and it takes over the role of market price as the driving force of economic development. Innovation competition replaces price competition in the market as the coordination mechanism of interest. Though price is still important in the market, it is not central to economic development. The economy which relies on input resources and price signals alone is not effective in stimulating productivity gains nor economic development. The goal of all economic policies should be the promotion of higher productivity through greater innovation and promotion of entrepreneurship. Modulating business cycles or economic fluctuations should take the innovation cycle into account.

Neo-Schumpeterian Economics combines elements of the original Schumpeterian Economics with ideas from evolutionary economics, complexity economics, system theory and industrial life-cycle disciplines. The synthesis states that aside from the Schumpeterian growth process of innovation and entrepreneurship, the economy is more of a complex biological system than a simple mechanistic system. This implies that interactions going on between different elements within the economic system are difficult to describe in a mechanistic input-output fashion. It also posits that the study of innovation must be approached through different layers (micro-, meso- and macro- levels) through a system study approach, and that it should take different industry environments into account as in industry life cycle study. The recognition of different layers in the economic system and the relevance of the industry life cycle make the use of simplified mathematical model difficult in neo-Schumpeterian analysis. Furthermore, neo-Schumpeterian analysis' emphasis on diversity also makes it unpopular with econometricians because it calls to attention the non-linearity and dynamic nature of innovations and their impact on the economy, making it hard to derive a fixed model[32].

However, neo-Schumpeterian economics' model-unfriendly nature and emphasis of environmental diversity are exactly why it is used as a framework in government economic policy. The attention to economic and innovation environments at the micro-, meso- and macro- levels make policy recommendations based on the discipline closer to the ground and more readily implementable.

The general policy recommendations of neo-Schumpeterian Economics are[33]:

- Emphasis on knowledge creation, diffusion and their transformation into innovation;
- The removal of constraints that inhibit economic factor input from reaching its full potential under the status quo;

[32] Paul Samuelson, who pioneer the analytical(mathematical) approach to Economics and dubbed "Father of Modern Economics", was a graduate student of Schumpeter at Harvard. Schumpeter was one of the best mathematician in the economics department at Harvard, it is interesting to note that he did not use mathematics in his innovation based economic growth theory.

[33] Hanusch, H., & Pyka, A. (2007). Principles of neo-Schumpeterian Economics. *Cambridge Journal of Economics, 31*, 275-289.

- Since qualitative changes within the economy happen in a punctuated fashion, policies should be flexible enough to handle both regular, stable periods as well as times of radical change;
- The dynamic growth process shows strong non-linearity and a positive feedback effect. Though the process is not easy to model, it does show a certain pattern and some form of structure. Economic policymaking should be based on the pattern observed.

The ideas of creative destruction from transformational technological revolution, creative accumulation from incremental innovation are associated with neo-Schumpeterian Economics.

F. China's current economic transition challenges:

From our discussion of economic growth process, an economy can grow by either employing more production inputs (labour and capital) or by becoming more efficient in order to derive more output per unit of input. The former is factor accumulation while the latter is productivity improvement[34]. For any economy, innovation and technological progress are the fundamental sources of its long term productivity growth. China's speedy growth in the past was essentially derived from a favourable combination of capital and labour factor accumulation with simultaneous productivity improvement. The high domestic savings and abundant rural labour force migrating to urban areas permitted the economy to use capital and labour factor accumulation to drive the economic growth. At the same time, technological progress associated with imported technology and initial market

[34] We use classical Solow model here in the discussion and assume human capital to be part of productivity to simplify discussion.

reform pushed economic growth further. However, China has now exhausted such easy "low-hanging fruits" and is facing higher and higher "Incremental Capital Output Ratio" (ICOR). On top of that, "demographic dividend" from rural labour force migration is exhausting. The factor accumulation path of economic development is running out of steam. At the same time, China must move to higher value-added activities and compete against its former imported technology provider, and the rivalry means that China cannot rely on convenient imported technology anymore to drive the productivity improvement side of the economic growth. Both capital efficiency and future productivity gains to drive the economy must come increasingly from its own R&D efforts[35].

In recent years, China has rapidly expanded its R&D activities, which reached 2.1% of GDP in 2014, compared to the 2.8% for the US and 3.4% for Japan. In absolute term, however, China's share of R&D spending is the second largest in the world and its GDP base is now number two in the world. In 2014, the "Nature Index/ Global" which tracks the sources of publication of high-quality scientific papers also ranked China second for publishing the world's largest number of high-quality scientific papers. The first is the US. With more than 3.5 million R&D personnel (seven times more than new university graduates every year) and an industrial base that is rapidly expanding and increasingly sophisticated, China is admittedly on track to develop a viable technological base that will eventually generate new sources of productivity increases to support future economic growth.[36]

[35] Wong, J. (2016). *Zhu Rongji & China's Economic Take-off*. Singapore: World Scientific Publishing Pte.

[36] Ibid.

We should note that a high R&D expenditure itself plus the training of a large number of high-level manpower do not automatically translate into successful commercial innovations and economic benefits. Many patents and inventions do not end up in successful commercial applications. They depend on the conducive institutional environment to help upgrade existing industries and foster emergence of new high value-added industries. Institutional innovation also involves the fostering of transformational type of leadership. Empirical observations on the emergence of innovative industries around the world points to the importance of transformational type of entrepreneurs such as Bill Gates and Steve Jobs in the US, Matsushita and Morita in Japan, Chung Ju Yung and Lee Byung Chul in South Korea.

G. Current Innovation Drive of China:

The Chinese government is consistent in promoting science and technology innovation since Deng Xiaoping's 1978 reform. In 1978, then-Vice Premier Deng announced in the joint meeting of National Conference on Science and Technology, the biennial conference of Chinese Academy of Science (CAS) and Chinese Academy of Engineer (CAE) that "science & technology (S&T) are productive forces"[37]. This change of state emphasizes on productive forces from proletariat workers to S&T intellectuals overturned Mao's dogma and ushered in spring for Chinese S&T development[38].

[37] The three in one meeting only happens twice in the history of People's Republic of China. The first one was the 1978 meeting with keynote speech by Deng and the second one in 2016 with keynote speech by Xi. Xi promised the government's full support to the innovations and independence of S&T development in 2016.
[38] Zhao, L. (2016). *CHIINA'S INNOVATION-DRIVEN DEVELOPMENT UNDER XI JINPING* (Rep. No. Background Brief 1143). Singapore: EAI.

Successive leaders after Deng have all used the National Conference of Science and Technology to unveil their strategies for S&T development. In 1995, Jiang Zemin announced the strategy of rejuvenating the nation through science and education (科教兴国战略). In 2006, Hu Jintao followed up on a strategy of building the country through human resources development (人才强国战略). All these attempts were focused on building the human capital base of S&T innovation.

At the 18th Communist Party Congress in which President Xi Jinping assumed China's leadership, the country officially endorsed the strategy of innovation-driven development. He was an enthusiastic supporter on innovation-driven economic growth and his speech on innovation was compiled into a book by the communist party's central committee literature research office. This book is titled "Excerpts of Xi Jinping's Remarks on Science and Technology Innovation".

In May 2015, the government announced the plan to move China to an advanced manufacturing country through *Made in China 2025*, listing 10 industries as focal points. At the end of 2015, the specified technological target in the 10 industries are published. In early May 2016, the country issued the Outline of the National Strategy of Innovation-Driven Development (国家创新驱动发展战略纲要). In the 13th Five-year plan adopted by the National People Congress on March 2016, innovation was the first objective mentioned in the "five-in-one" target to build a country of "innovation, coordinated development, green, open society and inclusive shared development".

Jiang and Hu's emphasis on human capacity build-up in their S&T policy has changed to emphasis on innovation under the incumbent Xi administration. In a way, the change in emphasis demonstrates the success of earlier human resources build-up, and shows that now is the time to harvest the developed human capital to meet China's changing economic challenges. President Xi had articulated that for China's ongoing S&T reform has only one objective. This is to "further breakdown the barriers between S&T and economic and social development"[39]. The Chinese government is pushing the integration of S&T innovation and economic development in an unprecedented way.

H. Using neo-Schumpeterian analysis in lieu of the Solow model

In our thesis, the choice of using neo-Schumpeterian analysis instead of the neo-Classical Solow model or its variant, the endogenous growth model, is attributable to the following reasons:

(1) All developed countries recognize the importance of innovation and entrepreneurship in driving the economy forward. Industrial development plan akin to *Made in China 2025* were adopted by all major industrial powers[40]. Though China is still a middle income country, it is the biggest manufacturing and manufactured goods exporting country in the world. The country already declared explicitly that innovation will be the driver of the economy going forward. The theoretical choice of studying innovation and entrepreneurship is always Schumpeterian model or its variant. There are many available resources on hand at industry (meso) and firm (micro) level from business schools around the world. Though these materials are mostly empirical in nature, they are accepted academically

[39] Ibid.

[40] *Industries 4.0* of Germany (2013), *New Industrial France* of France (2013), *National Network for Manufacturing Innovation* of US (2013), *White Paper for Manufacturing of Japan* (2014), *British Manufacturing 2050* of UK (2015), *Manufacturing 3.0* of South Korea (2014)

and often superior to mathematical models derived from Solow models in predicting outcome.

(2) Our thesis is going to answer the research question of whether China possesses the necessary conditions for success in its 4th Industrial Revolution Plan, *Made in China 2025.* The plan is an industry base plan and the Solow Model is a generic macroeconomic input-output model. Solow model cannot work at industry level, while neo-Schumpeterian meso-level industry study, working together with micro-level human capital innovators and macro level institutional reform, can provide a framework of analysis that can answer our research question. The empirical nature of the neo-Schumpeterian approach actually enhances its appeal to policy makers as it is closer to the ground with more policy recommendations as against to that of the Solow model or its variant. Moreover, the research question just looks at necessary conditions which give us rooms to use the empirical approach of neo-Schumpeterian analysis, in contrast to the sufficient conditions that often associate with rigorous mathematical techniques[41].

(3) Solow model is a mechanistic input-output model with capital, labour input modulated by TFP to generate economic growth. Though the breaking down of growth component into capital accumulation, labour accumulation and TFP gain are intellectually simple to grasp and indeed give succinct explanatory power of past growth performance. However,

[41] The future path of economic growth is often unpredictable even under the most rigorous mathematical modelling. Many economists consider the future economic path simply cannot be model. neo-Schumpeterian school consider the economic system as an evolutionary biological system rather than a mechanistic physical system and it cannot be model on current state of knowledge.

we had noted that TFP is a residual and it is essentially a black box that leaves the question of what makes up the TFP gain unanswered. Using TFP in an ex-ante study is hard to justify as we discussed earlier. We also noted earlier that the TFP index construction relies on some elasticity parameter assumptions further complicate the matter. For a typical low income country whose growth depends mostly on factor accumulation and TFP is not an important driver, Solow model is still workable. However, in the case of China that has a high historical TFP gain with its economy increasingly relying on innovation to move forward, the ignorance of TFP will definitely affect the study. On the other hand, innovation centric neo-Schumpeterian theory is designed to analyse economic growth in a country that is moving up from a high-middle-income country to a high-income country, especially from a longer-term perspective. It encompasses many critical variables in economic growth in that transition, including institution, human resources, entrepreneurship and innovation.

(4) Many Chinese scholars had identified the following factors behind the success of Chinese economic growth in the past: (1) Institutional reform that promote efficiency gain at micro-level and resources allocation, (2) Improved infrastructure, (3) Economic efficiency improvement through indigenous R&D and foreign technology adoption. These scholars also look at the following potential sources for continuing productivity growth in China: (1) Continuing institutional reform, (2) Emerging

entrepreneurship, (3) Increasing R&D-driven new innovations[42,43]. The Chinese government programs are designed to enhance the three potential sources of productivity growth. While Solow model does not look into those elements, these three sources of continuing productivity growth: Institutional reform, entrepreneurship and R&D driven innovation are all topics under neo-Schumpeterian framework of economic development. Using neo-Schumpeterian framework to look into our research question is appropriate.

(5) Chinese economy is transitioning from a high-middle income economy to a high-income one. Historically, out of 101 or so middle income economics in the 1960s, only about 13 (mostly in East Asia) had graduated to become high income economics by 2008. For the two East Asian countries since 1960 that had succeeded at such a rapid transition: South Korea and Taiwan. Their experiences have shown that innovation has played a key role in their successful transition to developed economy status. In some way, Chinese economy today is what these two countries are some years back. After a few decades of industrialization based on labour-intensive manufacturing, these two countries experienced labour shortages as well as losing comparative advantage for their manufacturing exports. They subsequently upgraded their industries, moved into higher value-added activities and became developed

[42] Wong, J. (2007). China's Economic Growth in East Asian Context. In *China's Surging Economy: Adjusting for More Balanced Development* (pp. 31-54). Singapore: World Scientific Publishing Pte. Ltd.

[43] Liu, Z. (2002). The Nature and Sources of Economic Growth in China: Is There TFP Growth? In *China's Economy into the New Century* (pp. 43-62). Singapore: World Scientific Publishing Pte. Ltd.

countries. China is now undergoing a similar economic transition. There are existing academic works using neo-Schumpeterian analysis to explain these countries' success. We can follow some methodologies used in these earlier works and confident of the outcome of the study.

(6) Earlier, we have discussed some generally-recognized policy recommendations based on neo-Schumpeterian economics. They provide some useful benchmark to test certain necessary conditions in this study.

(7) The idea of a punctuated, disruptive, and innovation-based economic development in China makes mathematical data-based projections of economic growth unfeasible. However, neo-Schumpeterian Economics has developed some necessary conditions for economic development. These conditions fall under three levels: micro, meso and macro[44]. All three levels are required to work systematically together towards economic development.

The micro-level encompasses human capital, entrepreneurial spirit, corporations that can provide entrepreneurship, and the innovation and execution capacity of firms.

The meso-level encompasses available entry opportunities to higher value-added activities for old industries, or available entry opportunities to gain access to new industries.

The macro level encompasses a government's effective acquisition of technology and stable macroeconomic policy.

[44] Lee, K. (2013). Chapter 6 – Toward a knowledge-based theory of economic catch-up. In *Schumpeterian Analysis of Economic Catch-up.* (pp. 127-146). Cambridge.

Choosing neo-Schumpeterian Analysis over New Structural Economics in the study

An alternative model for Chinese economic growth was proposed by the former World Bank chief economist, Justin Lin. This model, the New Structural Economics, aims to explain the country's economic growth by taking into account the reform-centric nature of China's economic growth pattern, and its discontinuous and mathematically unfriendly nature. It emphasizes the empirical study of comparative advantage and government policy that set the institutional and economic structure for growth.

New Structural Economics' hypothesis is that a developing country can take advantage of its backwardness and its comparative advantage of cheap labour to adopt foreign technology and accelerate economic growth opportunity. The model recommends that a developing country should just look at its comparative advantage and follow the growth or industrial policy of its peer in the next income bracket.

Empirical evidence suggests that New Structural Economics only applies to a country transitioning from a low-income to middle-income economy. In that transition, labour cost comparative advantage and foreign technologies are still around. When a country is moving from a high middle-income to high income status, rising wages and market competition from former providers of knowhow mean that the country must rely on indigenous innovation in its move to high value-added activities.

Out of 101 countries that have become middle-economies since the 1960s, only 13 of them (mostly relatively small economies) became developed countries by 2008. In East Asia, four "Little Dragons" - South Korea, Taiwan, Hong Kong and Singapore - successfully became developed economies. More than other countries, Taiwan and South Korea's successful transitions resemble that of China's. These two countries started in the 1960s at the low middle-income level, followed the export-orientation path during the initial stage, successfully move into high-value, innovation-based industries in 1990s, and became high income countries.[45]

In Korea, these high-value, innovation-based industries in 1990s are automobile, shipbuilding, steel, and consumer electronics. In Taiwan, they are semiconductors design and fabrication, PC, and IT. Both countries' growth are innovation-based industrial growth.

New Structural Economics and neo-Schumpeterian Economics are all empirically based studies. However, it is more relevant to use the neo-Schumpeterian framework in our research study of necessary pre-conditions of success of the industrial plan, *Made in China 2025*.

Research Question:

Under its 4th Industrial Revolution plan, does China have the necessary pre-conditions to transform into an innovation-driven economy?

Relevance of Research Question:

1. From approximately 10% in 2012, China's economic growth rate has slowed down since then to around 7%. Aside from the headwind of global slowdown, China is facing structural transition issues in moving from a high middle-

[45] Lee, K. (2013). Introduction. *Schumpeterian Analysis of Economic Catch-up* (pp.3-24). Cambridge, UK: Cambridge.

income country to high-income country. The government is pushing innovation to rejuvenate growth momentum. Hence, the research question is relevant to China's objective.

2. With close to 14% of global GDP in 2015, China contributed between 25% to 35% of annual global growth after the 2008 global financial crisis. Its importance to global growth is more than its share of the global economy, highlighting that it is an important driver of global economic growth. A dynamic Chinese economy has implications for other economies.
3. An Industrial Revolution is a period of significant improvements in productivity and economic transformation. Past experiences have shown significant spill-over effects from successful innovators to peripheral ones. China is the top manufacturing country in the world and positive externalities for its trading partners from successful innovation in China can happen quickly.
4. Every industrial revolution defines a new international economic order. Different countries adopt new technologies in neither the same way nor the same speed. Some will emerge leaders in the adoption process but some will lag behind. During the 1st Industrial Revolution, Great Britain emerged as the leading country. During the 2nd Industrial Revolution, the US came first, followed by Germany. During the 3rd Industrial Revolution which was based on digitization, the US again reinforced its global leadership position. Today, China is the most aggressive country in pushing innovation, and its success or failure in transforming its economy will have significant geo-political implications.

5. The research question looks into whether China can get the necessary pre-conditions for transformation into an innovation-driven economy. This means that careful examination of these conditions is required. In the last decade, China had moved from a simple assembler type of exporter to a supplier of highly technical products such as telecommunication gear[46]. Many countries will like to look at these necessary conditions as they can serve as a valuable policy reference tool.

Importance of the Research:

The research looks into whether China can get the necessary pre-conditions for success in its 4th Industrial Revolution Plan using neo-Schumpeterian Analysis. The conventional approach in studying economic growth problems is using the Solow model. To some Chinese economists, it is New Structural Economics. We argue that the proper framework to analyse such forward looking question should be neo-Schumpeterian. This change of perspective is very important in turning development economics into a forward looking science and that will be our contribution to the discipline.

Empirical historic evidence had shown that economic growth in developed countries is an industrial growth process. The ability to innovate and add more value to existing industries and to set up new high value-added industries, are the essence of the industrial growth process. The search for a working model that can shed light on the industrialization process is always an academically challenging topic, and our research aims to add to the knowledge in this important area. The model

[46] Fox, J. (2016, July 28). Huawei Conquers the World, Except the US. Retrieved July 28, 2016, from http://www.bloomberg.com/view/articles/2016-07-26/huawei-conquers-the-world-except-the-u-ses/2016-07-26/huawei-conquers-the-world-except-the-u-s

developed in this paper shows that industrial meso-level analysis using neo-Schumpeterian framework can provide good predictive value on necessary pre-conditions in the industrial growth process. The model could be useful for many scholars and policy makers and it is another contribution to the discipline of development economics.

It is noted that most of the economic growth programs in developing countries are essentially industrial growth programs. However, these programs are often top-down, taking consideration only from macro and some meso factors, with little attention to the micro-level pre-conditions for its success. The necessity of all the different elements in the three levels- is critical for the success of the industrial program. The research result in the paper highlights this important coordination issue and addresses an important gap in the current economic planning process.

Chapter 2 - Literature Review:

To properly understand our research question and the methodology applied in the thesis, this literature review focuses on three areas: some unique features of the Chinese economy, the 4th Industrial Revolution and China's 4th Industrial Revolution Plan, and the neo-Schumpeterian framework of Development Economics. These three focuses provide the basis to understand the rationale behind the methodology in answering the research question.

The Chinese economic growth process does not quite fit into a textbook case and a review of its unique features will highlight the facts that the country was not a typical third world nation with little indigenous technology and innovation capacity when it started the economic reform in 1979. The Chinese economy had demonstrated high total factor productivity growth and speedy ascension in technology ladder as witnessed by its speedy growth in high technology world export market in the reform era. The scale of R&D spending is contrary to the conventional thinking that China is a simple copy-cat technology follower. In relation to our research question, we have shown that China has been persistently building up its capacities in the elements necessary for success at micro-, meso- and macro- levels in the economic development analysis under neo-Schumpeterian framework since the reform started in 1979.

The research question studies the necessary pre-conditions for implementing *Made in China 2025*. The idea of 4th Industrial Revolution was first mentioned in 2013 and China's 4th Industrial Revolution plan, *Made in China 2025*, appeared only in May 2015. Our discussion on these two topics will help in the proper understanding of our research question.

The third literature review focus on neo-Schumpeterian framework of Development Economics provides the necessary background information to understand the methodology used in the thesis.

Some unique features of the Chinese Economy:

1. In the past, a burst of economic activity always comes after institutional reforms. Understanding the Chinese economy requires an understanding of how its institutional framework affects economic development. The traditional approach of using trends of economic input factors to look at output alone does not work well, because the burst of economic activities makes the intensity and timing of economic development hard to predict. Hence, developing mathematical models on Chinese economic development is not easy, and many economists still prefer a descriptive approach.
2. Given China's well-documented sky-high savings and investment rates, one might think that capital deepening is the most important factor in economic development. Though capital accumulation is the key factor in the development process (fig 7 below), it is interesting to note that total factor productivity also contributed significantly to the growth process along the way, and that labour deepening was only important at the initial stage. China's economic structure, with 30% of its economy in manufacturing and a significant portion destined for export, subjects itself to constant pressure on innovation in order to maintain its position as the "factory of the world".

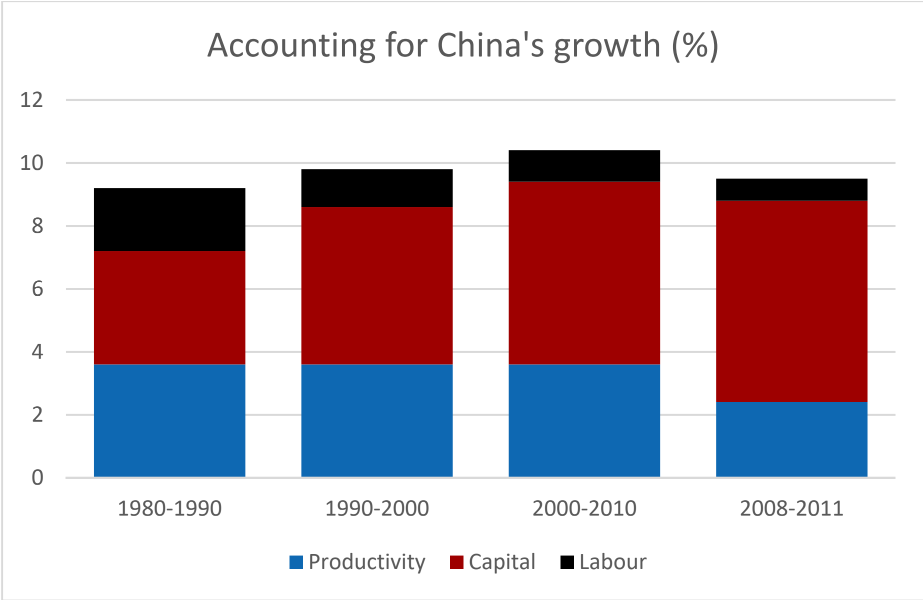

Fig 7. Accounting for China's growth[47]

3. Based on empirical observations, many traditional economic theories on technology and investment migration - such as the "Flying Geese Model" and the "Industry Life Cycle" – do not work for China. Besides the popular explanation that a good ecosystem somehow ameliorates rising wages and causes migration towards the interior rather than abroad, the productivity drive at the micro-firm level should not be overlooked. Fig 8 below shows that even as Chinese manufacturing developed to encompass new high-tech, value-added activities such as telecommunications equipment as well as traditional higher value-added activities such as automotive components and chemicals, Chinese firms maintained their global export market shares in textile and clothing. Exporting as the "factory of the world" exposes Chinese manufacturers to global competition, and their ability to maintain their market share indicates

[47] Liu, Z. (2015). Is China's Growth Miracle Over? Federal Reserve Bank of San Francisco Economic Letter. Retrieved from http://www.frbsf.org/economic-research/publications/economic-letter/2015/august/china-economic-growth-miracle-slowdown/

that their productivity must be constantly adjusting to the global cost structure. The huge domestic market, large population and skill pool allow multiple economic engines to work at the same time, subject to less input constraints.

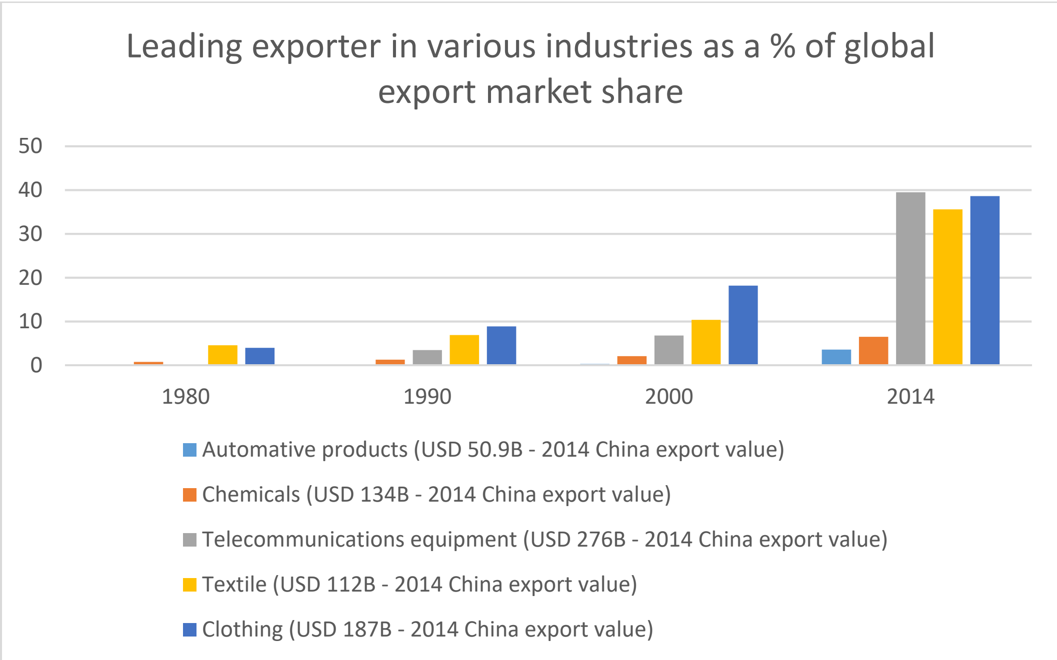

Fig 8. China's export data (WTO database and author's calculation)[48]

4. As indicated in fig 3, China's share of the export and import trade on goods as a percentage of GDP peaked at 64.5% in 2006. This dropped to 41.5% in 2014 and is still decreasing. The re-orientation of the economy to a more domestic one benefits the initial phase of an innovation economy, as the domestic market is generally more assured for new products. Government purchases are often the best way to nurture innovation.

[48] World Trade Organization. Time series – Subject selection. Retrieved from http://stat.wto.org/StatisticalProgram/WSDBStatProgramSeries.aspx?Language=E

5. The World Bank's records show that China's high-tech exports have increased consistently throughout the year. This can be seen in fig 9 below.

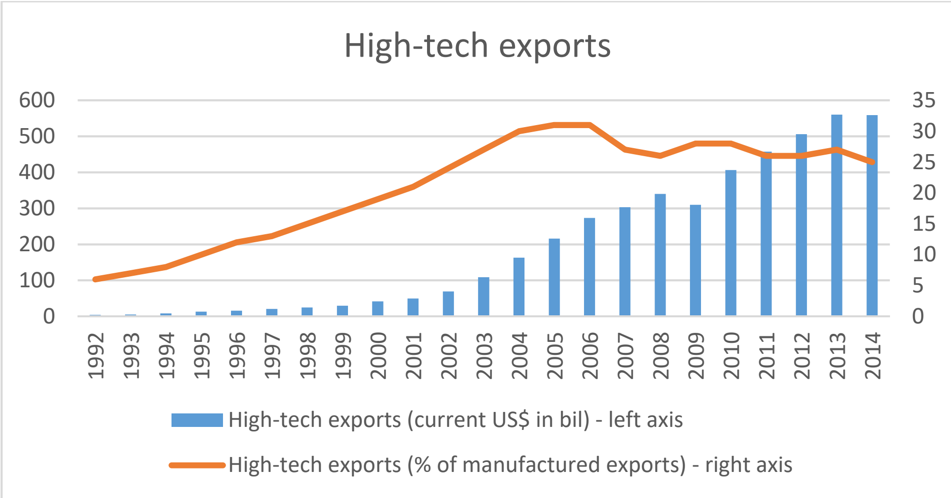

Fig 9. High-technology exports (5 of manufactured exports) and High-technology exports (current US$)[49]

Moreover, the latest release of data for Trade in Value Added (TiVA) shows that China is also the leading source of value-added manufacturing (fig 10). The percentage gap between its gross export share of global trade and domestic value-added in foreign final demand is rather close, indicating significant local content for its manufacturing export. This indicates that China has graduated from a mere export-processing type of manufacturing with significant raw materials, parts and components sourced from overseas to more indigenous technology-based exports.

[49] The World Bank. (2016). High-technology exports (current US$). Retrieved from http://data.worldbank.org/indicator/TX.VAL.TECH.CD/countries/CN?page=4&display=default

The World Bank. (2016). High-technology exports (% of manufactured exports). Retrieved from http://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS/countries/CN?page=4&display=default

Fig10. Top 10 suppliers of manufactured goods on gross export and value-added terms (2011)[50]

6. In terms of per capita income, China belongs to the high middle-income category and is definitely a developing country. However, its enormous spending on R&D often puts it on the technological frontier. Fig 11 shows that China was the second biggest spender on R&D in 2013, spending USD 318 billion in constant 2010 USD-constant prices and PPP terms compared to the US' spending of USD 433 billion. In this context, China might possess more technological prowess than commonly thought. The key to translating R&D results into economic development lies in the entrepreneurship that will facilitate the commercialization of innovations.

[50] OECD. (2015). Top 20 International suppliers of manufactured goods in gross export and value added terms, 2011. Percentage shares of total world manufactured goods. Retrieved from http://dx.doi.org/10.1787/888933273121

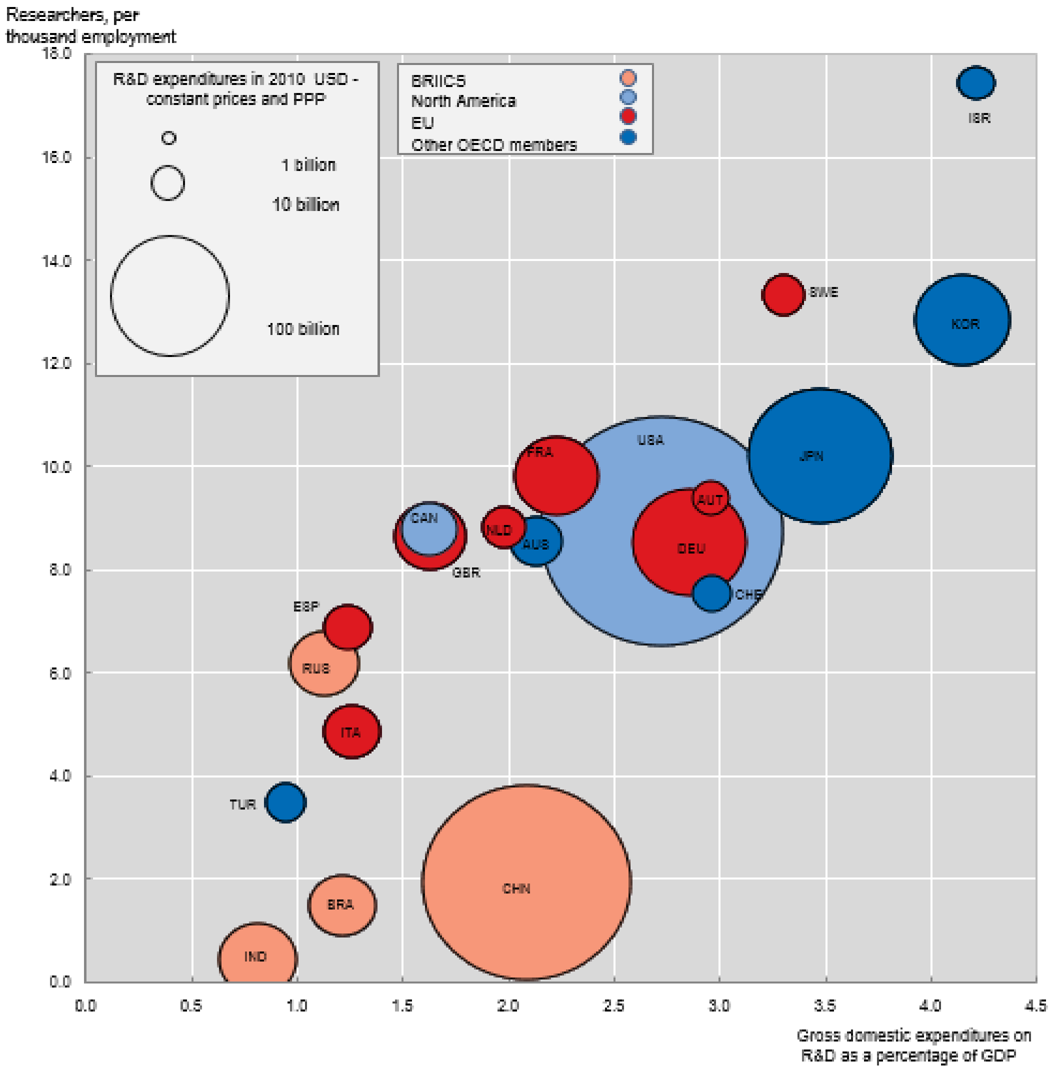

Fig 11. R&D in OECD and key partner countries, 2013[51]

4th Industrial Revolution & China's 4th Industrial Revolution Plan

The concept of the 4th Industrial Revolution started from an initiative called *Industry 4.0* to promote the competitiveness of German manufacturing industries. It was unveiled during the 2011 Hannover Fair by a group of German business and academic leaders. At the 2013 Hannover Fair, the German government officially

[51] OECD. (2015). R&D in OECD and key partner countries, 2013. OECD, Main Science and Technology Indicators Database. Retrieved from www.oecd.org/sti/msti.htm and UNESCO Institute for Statistics, June 2015.

adopted the group's report *Industry 4.0 Strategy Proposal* as a blueprint for industrial development. The idea received worldwide attention and many governments subsequently adopted similar industrial development plans: *New Industrial France* (2013); *National Network for Manufacturing Innovation* of the US (2013); the White Paper *for Manufacturing* of Japan (2014); *British Manufacturing 2050* (2015); *Innovation in Manufacturing 3.0* of South Korea; and *Made in China 2025* (2015).

The aim of *Industry 4.0* is to bring together a collection of technologies and concepts of value chain organization to build a smart manufacturing system, i.e. applying the tools of information technology to production. This primarily means using the cyber-physical system, Internet of Things (IoT) and the Internet of Service, to better integrate small and medium-sized German companies into global production and innovations via smart IT infrastructure.

Industrial Revolution (IR) refers to the totality of changes in economic and social conditions caused by a change in the technologies underlying the economy at that time. It is marked by a burst of general purpose technologies (GPTs), which are transformational technologies that carry new, deep ideas or techniques that can benefit a good number of industries. GPTs can sharply boost the productivity of an economy, and their emergence and convergence indicate that an industrial revolution is a period of intense creative destruction.

A good definition of IR is proposed by Nicolas Davis, Head of Security and Innovation at the World Economic Forum. He uses improvements in automation and connectivity to describe each IR[52]. The four industrial revolutions are shown in fig 12, and their descriptions are provided below.

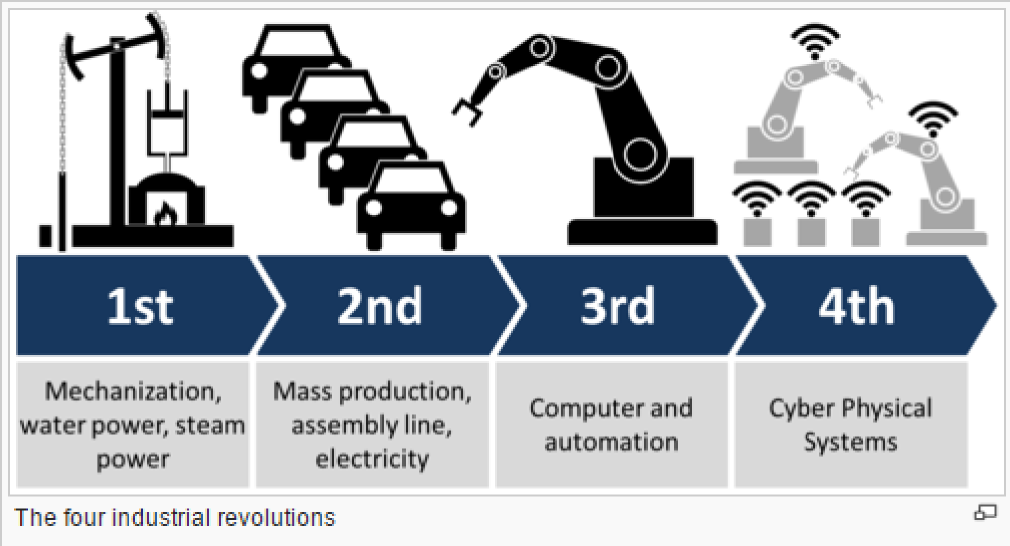

Fig 12. The four industrial revolutions[53]

In lieu of animal power, the first IR introduced early automation through machinery. Mechanization became a key element of economic development, and steam power and the locomotive revolutionized travel and improved physical connectivity.

The second IR was characterized by three factors: a higher level of automation via mass production; more efficient connectivity in production through the division of labour; and new energy sources such as electricity and oil. The second IR heralded standardization, the global supply chain and the modern corporation.

[52] Baweja, B., Donovan P., Haefele, M., Siddiqi, L., & Smiles, S. (2016). *Extreme Automation & Connectivity: The Global, Regional & Investment Implications of the 4th Industrial Revolution* (Publication). UBS.

[53] Roser, C. Industry 4.0 *The four industrial revolutions.* Retrieved from https://en.wikipedia.org/wiki/Industry_4.0

The third IR was marked by digitization. The scope of automation was enhanced by the exponential growth of computing power that can automate complicated tasks, and connectivity among people improved with the Internet.

The shape of the fourth IR is yet to come, but there are already signs that artificial intelligence and wireless telecommunication will be the key GPT. Extreme automation will expand the jobs that machines can handle, robots will increasingly take over jobs that only humans can do, and instantaneous wireless communication will allow remote control of many operations.

The idea of industrial revolution is an expansion of *Industry 4.0* and involves other aspects aside from manufacturing technologies. The various industrial development plans by the countries mentioned above (France, the US, Japan, the UK) concentrated on manufacturing but not on machine-labour substitution. Except for China, all nations that planned for the Fourth Industrial Revolution are developed countries.

The 4th Industrial Revolution implementation plan - *Made in China 2025* - is a top-level design roadmap to transform Chinese industries characterized as just being large to ones that emphasize overall leadership. The official start-up document was released by the State Council in May 2015, and a detailed technological roadmap (Green Book) was released in October[54]. This plan is the

[54] The Chinese government normally published its regular five-year plan as white paper with technological roadmap treated as an appendix of the white paper. In the case of *Made in China 2025*, the original document promulgated in May 2015 by the State Council was dubbed the White Book, and the technological roadmap published in Oct 2015 was dubbed the Green Book on the insistence of the Prime Minister as the cover of the 184 pages long report is colour green. The Prime Minister used the term Green Book to emphasize the point that the technological roadmap is formulated not by bureaucrats but scientist and industry players and unusually detailed. Chinese Academy of Engineering set up a regular office to monitor the progress and it is going to make biannual amendment to reflect new technological changes. *Made in China 2025* is a technology

first part of a 30-year project to improve China's global industrial leadership. The official document mentioned some broad targets for innovation, manufacturing efficiency, digitization and green economics. The Green Book is more specific and contains a roadmap for development for 10 key industrial sectors. The key sectors under *Made in China 2025* contain a good number of manufacturing sectors that properly belong to the Industry 2.0 and Industry 3.0 eras.

In a way, we can say that China is embarking on a road from Industry 2.0 to 4.0 under *Made in China 2025*, while at the same time filling some technological gaps between 2.0 and 3.0.

Made in China 2025 is wider in scope than all other countries' 4th Industrial Revolution plans, and it differs from the other plans in three key aspects:

1. It focuses on the entire manufacturing process and not just key innovations;
2. It promotes the development of not only advanced industries, but also traditional industries;
3. The plan is industry-based, with extensive participation by academics and research institutes. 48 academicians from the Academy of Science and Engineering, and more than 400 specialists from industry and academia participated in the drafting of the plan. The plan is subject to biannual review and evaluation, and the degree of high-level participation is unprecedented.

innovation centric industrial policy plan and it is the first time that the term Green Book is used in China.

Made in China 2025 is more than an industrial development plan based on technology innovation. According to President Xi Jinping, "we must…, implement the *Made in China 2025* vision, … to build a world-class manufacturing power, to provide strong strategic support for the realization of China great rejuvenation"[55]. The plan, *made in China 2025*, is a long term strategic economic development plan that is an integral part of a long term national development plan. The idea is to turn China from a manufacturing giant to an innovation giant. The popular slogan is to turn the Chinese goods from "Made in China" to "Created in China"[56]. Some broad targets on national innovation, manufacturing efficiency, digitization and green economics are mentioned. The advantage of being a strategic economic development plan over a technology innovation plan is the availability of more social resources to support the plan. *Made in China 2025* identifies 10 key industrial sectors with some sub-sectors as follows:

1. Advanced Information Technology - integrated circuit fabrication; communication equipment; operating systems and embedded industrial software; smart manufacturing network;
2. Computerized numerical machine tools and robotics - advanced machine tool manufacturing; robots;
3. Aerospace and Aeronautical Equipment - airplanes; jet engines; aerospace equipment and systems; new space equipment;
4. Maritime equipment and high tech vessels;
5. Modern rail equipment;

[55] Miao, W. (2015, July 10). Made in China 2025, the road towards the manufacture power. Retrieved September 8, 2016, from http://www.donghechina.com/news_detail/newsId=25.html
[56] Ibid.

6. New energy vehicles and equipment - new energy vehicles; energy saving cars; smart internet connected cars;
7. Power equipment - power plant equipment; transmission equipment;
8. Agricultural equipment;
9. New material - high-tech basic material; strategic material; advanced new material;
10. Biopharmaceuticals and advanced medical devices - biopharma; high tech medical devices.

China is one of the few countries in the world that still maintains official 5-year plans. However, *Made in China 2025* is different from earlier state-mandated 5-year plans in several key aspects:

1. There is still a focus on state involvement in funding and financing support, but market mechanisms and globalized technological exchange have become more prominent. One of the most important policy changes is technical standards. Instead of focusing on unique domestic technical standards, the attention is on self-declared standards by enterprises and the international standards system.
2. The Green Book technological roadmap for the 10 key industries is comprehensive, flexible and detailed. Targets set in the Green Book are based on China's current technological learning base and are very pragmatic.
3. The Green Book roadmap normally contains the following sections: market potential, objectives, key products, key technologies, showcase project, and strategic support required. Some reports also contain key

complementary technologies and products required. Interestingly, there are actually three time frames: 2020, 2025 and 2030. For technologies such as telecommunications where China is known as the leader, the guide post is set at 2020 and 2025, while for sectors such as semiconductor fabrication where China is considered lagging behind, the guide post is set at 2020, 2025 and 2030. This difference is apparently set to allow more learning time for the slower sector.

Neo-Schumpeterian Framework of Development Economics

Joseph Alois Schumpeter (1883-1950) was an Austrian-born American economist and political scientist famous for coining the term "creative destruction". This theory on economic development was not popular during his time, but it has gained attention in the last three decades following the emergence of new high-tech industries as the driver of economic development.

During the mid-1990s, the concurrent rise of a new, technology-driven economy in the US and the stagnation of other G7 countries like Europe and Japan revived the interest of both policy makers and academics in Schumpeterian innovation-based economics. The US' superior economic performance from the mid-1990s till the present, compared to other advanced G7 economies, is attributed to the concentration of technological innovation in the US[57]. Its subpar economic recovery after the 2008 global financial crisis pushed more and more advanced

[57] Furman, J., & Shambaugh, J., (2016). Chapter 5 – Technology & Innovation. In S. Black (Ed.), *Economic Report of the President – together with the Annual Report of the Council of Economic Advisors* (pp. 207-250). Doi: https://www.whitehouse.gov/administration/eop/economic-report-of-the-President/2016

countries to look at innovation- driven improvements in productivity as an alternate solution to stimulate demand and jumpstart their economies. The most popular recommendations were structural reforms to increase productivity of the underlying economy and pursuing innovation to improve productivity, which are essentially variants of neo-Schumpeterian schools. Prominent economists Larry Summers and Brad Delong declared the 21st century to be an age of Schumpeter studies[58].

Schumpeter's innovation-driven view of economic development has a huge following in business schools. His concept of "creative destruction" is one of the central ideas in most business schools' courses on innovation. Another central idea of Schumpeterian economics, "entrepreneurship", has evolved into one of the pillars in most business schools as well.

Technological innovation is a driver of economic development. Under Schumpeterian economics, the modern economy is always in a dynamic state of disequilibrium that is growing and changing all the time. It makes structural change the central problem of economics. Schumpeter posited that innovation, the entrepreneurship that moves resources from old and obsolete to new and more productive employments, is the very essence of modern economics. Schumpeter's economics is a study in innovation dynamics.

In Schumpeter's mind, the economy is in an initial state of stasis with a cyclical flow between the household and firms in a typical two-factor economy. This is illustrated in Fig. 6 earlier. An aspiring entrepreneur inspired by new ideas or

[58] Roberts, R. (2007). PERMANENT LINK | *October 8,2007 McCraw on Schumpeter, Innovation, and Creative Destruction* [Podcast]/ Library of Economics & Liberty. Retrieved from http://files.libertyfund.org/econtalk/y2007/Mccrawinnovation.mp3 6:24 -6:30

products comes into picture and introduces innovation into the economy. This move triggers economic development. The economy in turn rewards the entrepreneur with handsome profits and it will last until imitators come in and drive the margins down to its former state of stasis. The economy will experience a boom when innovation comes in, and a return to stasis or bust when new innovation dries up and old innovations wear out. Innovation is the cause of both economic development and cyclical instability.

Schumpeter maintained that innovations tend to cluster around certain points in time – what he called the "neighborhood of equilibrium". The burst of entrepreneurial activities is the period when entrepreneurs perceive risks, and potential returns warrant a commitment to innovation. An industrial revolution is a period when many new general purpose technologies appear and it is also typically a period of massive "creative destruction".

Innovation also means "creative destruction". The obsolescence of old equipment or investment means more new capital is needed. The economy then calls for capital formation and improvements in productivity to maintain its wealth-producing capacity. In a Schumpeterian development economy, only the innovator makes a genuine "profit" that is needed to maintain the capital formation required by the economy. This necessity of "profit" to maintain economic development is different from both classical and Marxist economics. Schumpeterian economics provide a moral ground for "profit". So one of its basic questions is: "Is there sufficient profit for adequate capital formation to handle creative destruction and provide for the future?"

Innovation drives the Schumpeterian economy.

The goal of economic policy should be the promotion of higher productivity through greater innovation, and modulating business cycles or economic fluctuations should take innovation cycles into account. Schumpeterian innovation areas are broad, and new things, or continual improvement, or the recombination of old things that can improve economic outcome are defined as innovation. More specifically, he defined innovation as:

- Introduction of new products;
- Introduction of new production methods;
- Opening up of new markets;
- Opening up of new sources of raw material;
- New organizational forms in any industry that improve economic outcome.

The entrepreneur is the agent of economic development.

Schumpeter maintained that invention and the implementation of innovation are two different things. Inventions or ideas that do not materialize are irrelevant.

The entrepreneur is at the center of innovation. He is motivated by:

- The desire to build a private commercial kingdom;
- The will to conquer and prove his superiority;
- The joy of creating, of getting things done, or simply exercising one's energy and ingenuity.

An entrepreneur also requires two things to perform his role:

- The existence of technological knowhow in order to produce innovation;
- The power of disposal over the factors of production, in particular credit, in the implementation stage.

Industry and firm competence is a platform for economic development. Schumpeter came to see entrepreneurship as a function that could be performed by a team or a corporation, not necessarily by an individual. He claimed that large corporate forms of organization are drivers of economic development, and he thought that any kind of organizational change could be an important factor in economic development.

Schumpeter's distinction between invention and innovation demonstrates the pragmatic dimension of his thinking. His emphasis on entrepreneurs is in essence an emphasis on implementation over pure ideas. His designation of the corporation as an effective agent of entrepreneurship shows his unconventional thinking, as popular academic thinking at that time associated corporations with monopoly. Schumpeterian economics differs from other schools in its emphasis on the platforms of implementation, be they entrepreneurs, firms or industry. This platform specific approach allows more focus on policy design and closer supervision of implementation.

Neo-Schumpeterian development economics

Economic conditions when Schumpeter passed away in 1950 were very different from today. The vertical corporation model that built up US industrial structures in the early 20th century was replaced by a combination of the dynamic start-up, declining numbers of small- and medium-sized manufacturing firms and giant multinational manufacturers working under the global value chain[59].

[59] Berger, S., & MIT Task Force (2013). Production in the Innovation Economy. *Making in America: From Innovation to Market.* MIT Press.

There are many meaningful additions to Schumpeter's original ideas, and neo-Schumpeterian economics is a synthesis of his original ideas and the infusion of ideas from evolutionary economics, complexity economics, the study of industries' life cycles, and systems theory[60]:

- Evolutionary economics emphasizes path dependency and irreversible events. To study the driving forces behind the emergence and diffusion of innovation, we must understand how heterogeneous rational actors learn by trial and error in uncertain environments to innovate. The outcome of evolutionary processes can neither be determined in an ex-ante way nor from the standpoint of global optimization. The economic system resembles an evolutionary biological system and not a mechanistic physical system.
- Complexity economics emphasizes the interaction between agents in knowledge generation and diffusion processes. The world is inherently complex, nonlinear and unpredictable, much more so in the area of innovation.
- Studying the industrial life cycle complements the application of neo-Schumpeterian economics in the setting of industrial development policy. It provides the idea of creative accumulation for mature industries in opposition to the creative destruction of new industries.
- Systems Theory provides the basis for studying the interaction of different economic actors in the innovation process: firms, universities,

[60] Hanusch, H. & Pyka, A. (2007). Principles of neo-Schumpeterian Economics. *Cambridge Journal of Economics*, 31(2007), 275-289.

and public research laboratories. It also enables the study of the institutional frameworks and governance structures that shape the innovation process in national, sectoral, regional and corporate innovation systems. Popular ideas such as the innovation cluster fall under systems theory.

In a nutshell, the neo-Schumpeterian Economics combines the original Schumpeterian idea of innovation driven economic growth with subsequent contributions from other disciplines. It deals with dynamic processes that transform an economy through the introduction of innovation in different forms.

Policy recommendations from neo-Schumpeterian Economics on economic development are generally[61]:

- Emphasis on the creation, diffusion and transformation of knowledge into innovation;
- Removal of constraints that inhibit economic factors of production from reaching their full potential under the status quo, and allowing these factors to develop under new circumstances;
- Qualitative changes to the economy happen in a punctuated fashion, and policy flexibility is needed to handle both stable regular periods and radical changing times;
- The dynamic growth process shows a strong non-linearity and positive feedback effect. Though the process is not easy to model, it does show

[61] Lee, K. (2013). *Schumpeterian Analysis of Economic Catch-up*. Cambridge, UK: Cambridge.

a certain pattern and some form of structure. It is not completely erratic; even innovation is characterized by strong uncertainty.

Chapter 3 - Research Methodology

To answer our research question, "*Does China have the necessary pre-conditions for its transformation into an innovation-driven economy under its 4th industrial revolution plan?"*, we will use the three level neo-Schumpeterian analysis framework to examine whether China possesses those necessary pre-conditions to succeed in all the three levels under the framework for its *Made in China 2025* plan. The three level analysis at the micro-level, meso-level and macro-level are the standard methodologies today in the discipline [62].

Using three level neo-Schumpeterian analysis to study innovation-driven economic growth:

The micro-level analysis refers to the basic human and firm base innovation capacity available in the society. At the micro-level, we examine human resources that complement entrepreneurs to form the knowledge base of firms. The learning and innovation capacities of the firm are the keys here. The idea of knowledge-based theory of production makes innovation a problem-solving activity and draws upon knowledge bases that are stored in firms' routines[63].

The meso-level refers to industrial level analysis and focuses on the challenges facing the establishment of a new high value-added industry or migrating to higher value-added activities in an existing industry. At the meso-level, we use the idea of the technological regime to define the particular situation which

[62] Lee, K. (2013). Chapter 6 – Toward a knowledge-based theory of economic catch-up. In *Schumpeterian Analysis of Economic Catch-up* (pp. 127-146). Cambridge.

[63] Grant, R. (1996). Knowledge based theory of the firm. *Strategic Management Journal, 1996(17),109.* Retrieved from https://www.researchgate.net/profile/Robert_Grant12/publication/229100915_Toward_a_Knowledge-Based_Theory_of_the_Firm/links/54da315a0cf24647582106cd.pdf.

a firm or an industry must tackle when it works on a particular technology. A technological regime puts a constraint on the pattern of emerging innovation in an industry. It is defined as a particular combination of four key factors: technological opportunities, appropriability, the accumulation of technical advances, and the property of the knowledge base.

- Technological opportunity refers to the extent a technological sector can draw relevant technological information from the knowledge base. The knowledge base can be in-house or from outside sources such as the technologies of suppliers or customers, or works by universities or research institutes. It indicates the likelihood of successful innovation for an investment. High opportunities provide powerful incentives for innovative activities and are indications of an environment that is not functionally constrained by scarcity. In the case of China, it means how likely China is to acquire the necessary technologies in the industry, either through indigenous technological breakthroughs or from foreign sources.
- Appropriability refers to the ability of the owner of a resource to receive a return equal to the value created by that resource. It indicates the possibility of protecting innovations from imitations. Possible devices of appropriability in the context of technological regimes are patents, the learning curve effect, differential technological efficiency due to the scale effect, and lead time. In China's case, it means how the reward opportunities in the target industry are like.
- Cumulativeness relates to the cognitive nature of the learning process (e.g. tacit knowledge, learning by doing). It reflects the extent of

dependence of today's innovation on past innovation. For China, it means how important accumulated knowledge is to current innovation efforts.

- The property of the knowledge base refers to the level of specificity of the knowledge required, whether universal and widely applicable, or specific to one area. It is important in the learning curve of a particular product or process. In the case of China, it means the kind of knowledge base needed for the current innovations in a particular industry. Is it a very broad general knowledge type which requires a lot of complementary technologies in order to put an innovation to use? Or is it a very specific area, in which once a particular breakthrough is achieved, innovation is done?

These four factors constituting the technological regime are the major ones, and there are other factors such as: relative cycle time (speed of obsolescence of knowledge), accessibility of external knowledge flows, initial stock of accumulated knowledge, and the uncertainty (fluidity) of technology's trajectory. How one define a technological regime really depends on the industry at hand[64].

Technological regimes play a major role in determining the specific pattern of innovation of an industry across countries. Through the major constraints identified by technological regimes, we can identify why some late comer countries succeed in catching up in some industries but failing in other industries. It determines the pattern of innovation for specific technological classes.

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[64] Park, K. (2006). Linking the Technological regime to the Technological Catch-up: Analysing Korea and Taiwan using the US patent Data. *Industrial & Corporate Changes, 16*(4). Retrieved from https://www.researchgate.net/profile/Keun_Lee10/publication/5212589_Linking_the_technological_regime_to_the_technological_catch-

The macro-level refers to government policies and actions that enhance the availability of the elements at the micro- and meso- level necessary for innovation to prosper. We will look at the government industrial and innovation policies at this level.

The technological and innovation capacities of states are the drivers of economic development for high-middle income and high income countries. We will study human capital and entrepreneurship at the micro-level, industrial catch-up using the technological regime at the meso-level, and government policies at the macro level to examine the potential of innovation to meaningfully contribute to China's economic development. These three levels complement each other and must work in tandem to provide the necessary pre-conditions for a country's success in setting up a new industry and use that industry to move the economic development forward.

Elements at the three level neo-Schumpeterian analysis:

At the micro-level – we use the following elements that push an innovation-type economy:

- Human capital - tertiary enrolment figures, R & D personnel numbers and budget, annual publication figures of scientific papers[65];
- Entrepreneurial spirit - a common proxy used is business formation[66];

[65] Fiscal Policies for Innovation & Growth. (2016). In *Fiscal Monitor Spring 2016* (pp. 29-50). Washington, DC: IMF. Retrieved from http://www.imf.org/external/pubs/ft/fm/2016/01.fmindex.htm

[66] Furman, J., & Shambaugh, J. (2016). Chapter 5 – Technology & Innovation. In S. Black (Ed.), *Economic Report of the President – together with the Annual Report of the Council of Economic Advisors* (pp. 207-250). Retrieved from https://www.whitehouse.gov/administration/eop/cea/economic-f-report-of-the-President/2016

- Corporations that can provide entrepreneurship – the size of a firm is positively correlated to its absorptive or innovative competence in the case of “creative accumulation” sectors. These sectors are the most prevalent sectors in the economy rather than “creative destruction” sectors. The increasing size of large corporations and the increasing trend of patent filings prove these points. Higher levels of manufacturing value also demonstrate corporate technical strengths[67]. In an Asian setting, giant corporations also push creative destruction-type innovation.
- Innovation capacity - to prove that there is a micro-level indigenous capability to innovate, we show that the patent holdings of domestic firms are increasingly dominant over foreign firms, and business patent activities are increasingly dominant over that of individual’s[68].

There are a number of good secondary databases regarding these elements and we will use them in the analysis. We will also use published patent application information from the World Intellectual Property Organization’s (WIPO) Patent Cooperation Treaty (PCT) to identify Chinese technological leadership in 35 technological fields.

At the meso-level - to check the available entry opportunities to higher value-added activities in old industries or to gain entry to new industries, we use the *technological regime* framework.

[67] Lee, K. (2013). Chapter 8 – Catching up and leapfrogging in China & India. In *Schumpeterian Analysis of Economic Catch-up* (pp. 178-201). Cambridge.

[68] Ibid.

The technological regime as a framework comprises of four criteria: technological opportunities; appropriability; the cumulativeness of knowledge; and the knowledge base. We use them to study the pattern of innovation in the Chinese high speed rail industry and develop a technology and market innovation model[69].

This approach emphasizes the role of technological learning and the absorptive capacity of the learner in the dynamics of industrial upgrading. This is in sharp contrast to the conventional economic return base theory of the industry life cycle. The industry life cycle theory posits that as a technology ages and loses its formerly high margin, it will automatically migrate to new comers who are willing to work at a lower margin. We have noted the persistence of technological leadership in certain industries, such as German machinery industries which operate on lean margins. This approach is the dominant approach now used in neo-Schumpeterian analysis on sectoral innovation.

Our application of the technological regime follows that of Rho in his analysis of China's semiconductor industry and that of Mu in her analysis of the Chinese automobile and telecommunication sectors[70, 71]. We also use the

[69] Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological Regimes & Schumpeterian Patterns of Innovation. *The Economic Journal, 110,* 388-410.

[70] Rho, S., Lee, K., & Kim, S. (2015). Limited Catch-Up in China's Semiconductor Industry: A Sectoral Innovation System Perspective. *Millennial Asia, 6*(2), 1-29.

[71] Mu, Q., & Lee, K. (2005). Knowledge diffusion, market segmentation and technological catch-up: The case of the telecommunication industry in *China Research Policy, 34,* 759-783. Retrieved from http://ac.els-cdn.com/S0048733305000946/1-s2.0-S0048733305000946-main.pdf?_tid=a799789e-0a97-11e6-bdf3-00000aacb361&acdnat=1461555895_22ed320f5c27866d3e3488f55519fddb

information drawn from *Made in China 2025*'s Technological Roadmap (The Green Book)[72].

We will use the framework of the technological regime to look at one of the industry in *Made in China 2025*- modern rail equipment. The high speed rail industry development story in China demonstrated the pattern of innovations in the building up of a technologically challenging industry. We have developed a model on the technology and market innovation on high speed rail in China. This model can serve as a guide post to future studies of success pre-conditions of an industry.

The real dynamics of innovation occurs at the industrial level. Information from the PCT complements the stated information in the Green Book and helps us to answer the research question.

At the macro-level, we look at various technological acquisition schemes of the government and their support to the industry at the meso-level on its quest for appropriability, cumulativeness and acquisition of proper knowledge base in building the new industries. The government also plays a critical role in fostering the human capital base and entrepreneurship micro foundation.

Expected outcome in the findings at three levels of neo-Schumpeterian analysis:

To use neo-Schumpeterian analysis to answer the research question: "Under its 4th Industrial Revolution plan, does China have the necessary pre-conditions to transform into an innovation-driven economy?", we look at whether

[72] China Strategic Industry Council 国家制造强国建设战略咨询委员会 (2015). Technology Map for Made in China 2025 *《中国制造 2025》重点领域技术路线图* (pp. 1-184, Publication). 北京: 国家制造强国建设战略咨询委员会.

China possesses the necessary elements for the success of innovations at the three levels of analysis.

At the micro-level, does the country possess the required four elements of human capital and its related output, entrepreneurial spirit, corporate entrepreneurship, innovation and execution capacity of innovators. These elements form the basic innovation capacity of the country. The findings at the micro-level will be presented in Chapter 4.

At the meso-level, we study the industrial development case on one of the ten industries under *Made in China 2025*- the high speed rail (HSR) industry. We develop a model on technology and market innovation on HSR in China based on neo-Schumpeterian framework. We look at whether the model remain valid today under different sets of economic conditions. The validity of the model provides the pre-conditions to succeed in the *Made in China 2025*.

The findings at the meso-level will be presented in Chapter 5- Research Findings at the meso-level of neo-Schumpeterian Analysis.

At the macro level, we will look at the overall government efforts in promoting national capacity building at the micro-level and promote industrial policies setting at the meso-level. An active government in these two areas is the pre-condition of success at the macro-level for neo-Schumpeterian analysis.

The findings at the macro level will be presented in Chapter 6-Research Findings at the macro-level of neo-Schumpeterian Analysis.

The elements at the three levels of analysis must work together to deliver a good outcome. They are interacting in a dynamic way and the missing of any single element in the elements will adversely affect the answer to our research question.

Chapter 4 - Research Findings at the micro-level of neo-Schumpeterian analysis

This chapter reports the findings on China's progress in the four areas of human capital and its output, entrepreneurial spirit, corporate entrepreneurship, innovation and execution capacity of innovators under the meso-level analysis. According to the neo-Schumpeterian analysis, these micro-level elements needs to be in place for a country to become an innovation driven economy. The objective of this chapter is to examine the state of China's micro factors, and provide an assessment as to their adequacy by evaluating them against the performance of other economies.

Introduction to Findings:

The three levels of analysis provide an integral framework to evaluate whether China possesses the necessary pre-conditions to succeed in its *Made in China 2025* plan under neo-Schumpeterian analysis. The micro-level provides national innovation capacity, the meso-level turns the available innovation capacity to tangible products under the favourable macro-level industrial economic environment. The three-level analysis are related and they must work together in answering the research question. We will discuss the micro-level findings in this chapter and analyse meso-level in chapter five and macro level in chapter 6.

There are four elements in the micro-level analysis and they provide the foundation in building the innovation capacity of a country. We look at the following four elements in the evaluation of a country's innovation capacity at micro-level.

The first element - human capital and its related output provides the foundation for innovation potential of a country. There are several parameters used in gauging this element. The first parameter is tertiary enrolment. It is a parameter used to estimate the potential size of human resources pool that can meaningfully contribute to innovation driven economy. The second parameter is the number of scientific researchers & research budgets. This parameter serves as a good proxy on the potential of innovation output. The third parameter is the number of returning overseas talent. This is a new parameter that was introduced in recent years with the increasing mobility of top rated research talents. It represents the attractiveness of domestic R&D environment to high calibre science talent. In the thesis, we use the international net flows of scientific authors complied by OECD as the proxy. The fourth parameter is the number of scientific and technical journal publications. This is a good indicator of innovation output. The fifth parameter is the quality of scientific research output as measured by the country's scientific publication in top citation tier in their respective fields.

The second element-entrepreneurial spirit is represented by business formation data. This represents the potential pool of motivated entrepreneurs to turn innovations into business success.

The third element- corporate entrepreneurship is represented by the trend of increasing corporation size as measured by sales. Anecdotally, neo-Schumpeterian economists have noted that there is a paradox in the patent arena since the 1980s. While the percentage of patents going to new start-up is increasing. The concentration of patents in terms of number of patent on the hand of giant corporation also increases. There is a hollowing out at the middle ground[73]. Anecdotally, we can explain the phenomenon by noting that start-up is always good at innovation as their formation is often related to the emergence of new technology. The 1980s herald in a period of high-tech innovation. While in the case of the large corporations, their management have realized that R&D are necessary investment in keeping up their dominance in the industry. These two factors are clearly absent in the medium size business. Corporation is an important element in the innovation landscape of a country and increasing sales is often a good precursor to increasing R&D spending and innovation. Under *Made in China 2025*, the Chinese government mandated that large manufacturers must increase R&D spending from 0.95% in 2015 to 1.26% in 2020 and 1.68% in 2025. The government also mandated that large manufacturers' patent numbers must increase from 0.44 per RMB 100m of sales in 2015 to 0.70 in 2020 and 1.10 in 2025. Corporations are important agents in turning innovation to economic growth and Chinese government is pushing the large corporation to increase their commitment to R&D and innovation.

The fourth element- innovation and execution capacity of innovators are analysis using patent data. The gauge of a country's innovation power and potential monetizing power of innovation are represented by its increasing patent portfolio in both domestic and international PCT filing, increasing business holding of patents over individuals, and its position in key patent areas as compared to other peer countries.

Micro-level analysis:

[73] Smith, D. (2010). Sources of innovation. In *Exploring Innovation* (pp. 85-99). Berkshire, UK: McGraw-Hill.

Human Capital:

- Tertiary enrolment - fig 13 below indicates the enrolment level of tertiary students in China from 1984 to 2013. From 2% in 1984, the figure increased to 8% in 2000, 24% in 2010 and 30% in 2013. Its increasing tertiary enrolment puts China on par with advanced countries now.

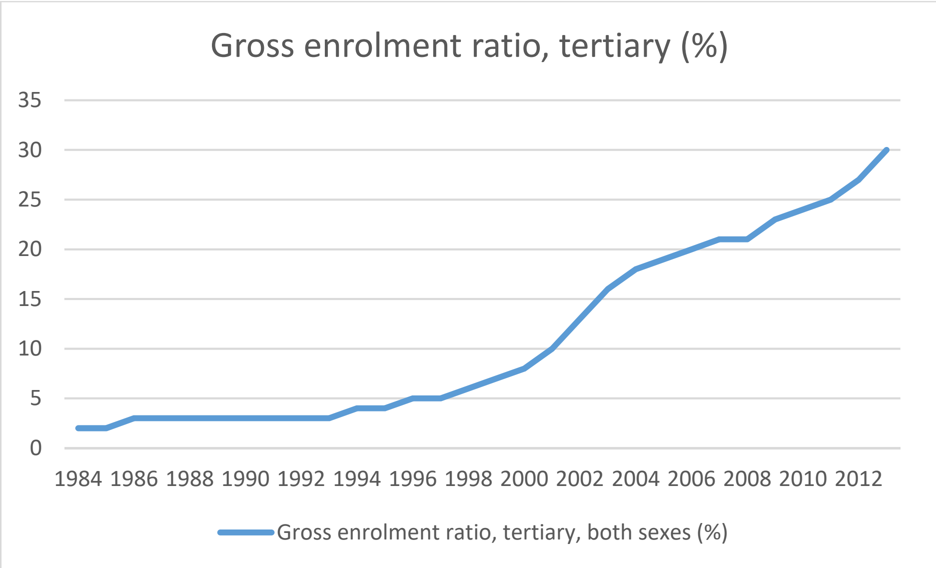

Fig 13. China's gross enrolment ratio, tertiary (%)[74]

- Number of scientific researchers and budget - fig 14 indicates that the number of researchers and research budget show a consisting pattern of increase. Together with fig 11's data from OECD based on 2013 data, this shows that China is rapidly increasing its commitment to R&D. The government is committed to a R&D budget of 2.5% GDP in 2020 with basic science going from 5% to 10% in R&D spending.

[74] The World Bank. (2016). Gross enrolment ratio, tertiary, both sexes (%). Retrieved from http://data.worldbank.org/indicator/NY.GDP.PCAP.CD/countries/CN?page=6&display=default

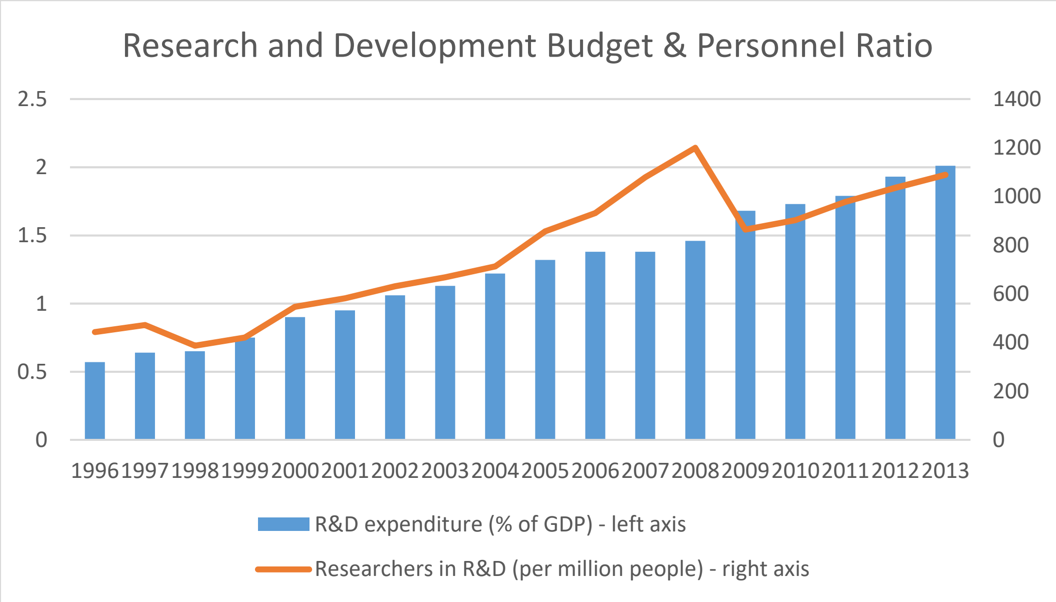

Fig 14. China's Research and Development[75]

- Research talent augmented by returning overseas talents[76] - the table below indicates international net flows of scientific authors of selected economies between 1999-2013, as compiled by OECD, and based on Scopus Custom Data. The estimates are based on the difference between implied inflows and outflows of scientific authors for the reference economy, as indicated by a change in the main affiliation of a Scopus ID over the author's indexed publication span. The table below reflects the flow of scientific authors from the five largest net gaining countries and five largest net losing countries out of 25 countries in the database.

[75] The World Bank. (2016). R&D expenditure (% of GDP). Retrieved from http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?page=3

The World Bank. (2016). Researchers in R&D (per million people). Retrieved from http://data.worldbank.org/indicator/SP.POP.SCIE.RD.P6?page=3

[76] China had one of the most active program attracting returning scientist. For more details, look at Yu, W. (2002). China's Drive to Attract the Return of its Expatriate Talent. In J. Wong (Ed.), *China's Economy into the New Century* (pp. 387-404). Singapore: National University of Singapore.

Period	1999-2003	2004-2008	2009-2013	Total
US	11836	615	-2457	9994
China	-902	4052	6083	9233
Switzerland	997	2051	4923	7971
Australia	34	1446	4605	6085
South Korea	814	1743	1209	3766
India	-2390	-3170	-1334	-6894
Italy	-889	-1739	-5449	-8077
Japan	-1782	-3398	-3594	-8774
France	-3046	-3214	-2505	-8765
UK	-2298	-2956	-6297	-11551

Fig 15. International net flow of scientific authors[77]

- China's scientific and technical journal output has also shown a marked increase since 2013, and the trend continues today (figure 16).

[77] OECD Science, Technology and Industry Scoreboard 2015. *International net flows of scientific authors, selected economies, 1999-2013.* Retrieved from http://dx.doi.org/10.1787/888933273360

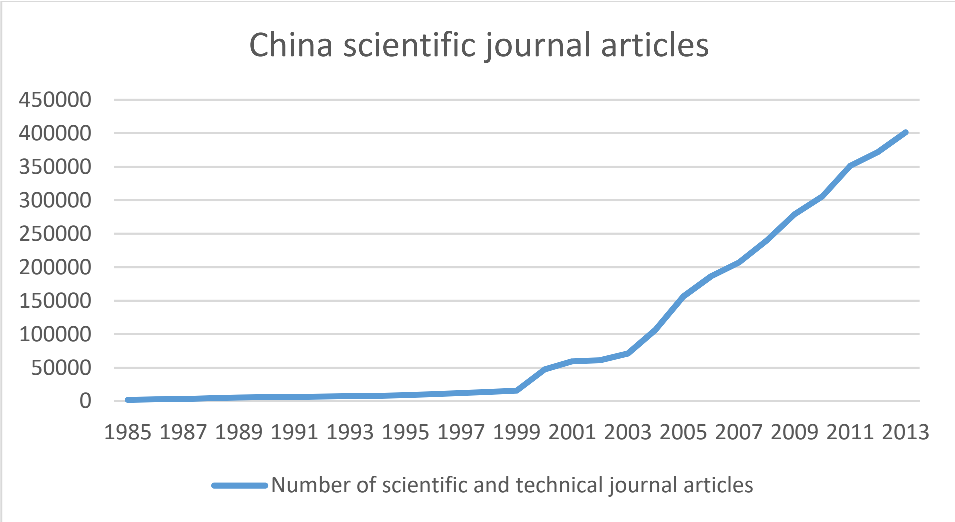

Fig 16. Scientific Journal Articles Output[78]

- The quality of Chinese scientific journal articles is improving - China is now one of the top 4 publishers in 11 out of the 25 disciplines monitored by the OECD. The fields where China is not included in the top 4 are: social sciences - psychology, economics, business, arts and humanities; biological sciences and health care - neuroscience, biochemistry, medicine, immuno- and microbiology, dentistry, veterinary, agri- and bio-sciences; health care - nursing, health professions; earth sciences. The US is the leader in all 25 disciplines. Fig 17 shows the breakdown of countries in which China is the top 4 for the largest number of 10% top-cited publications.

[78] The World Bank. (2016). Scientific and technical journal articles. Retrieved from http://data.worldbank.org/indicator/IP.JRN.ARTC.SC/countries/CN?page=6&display=default

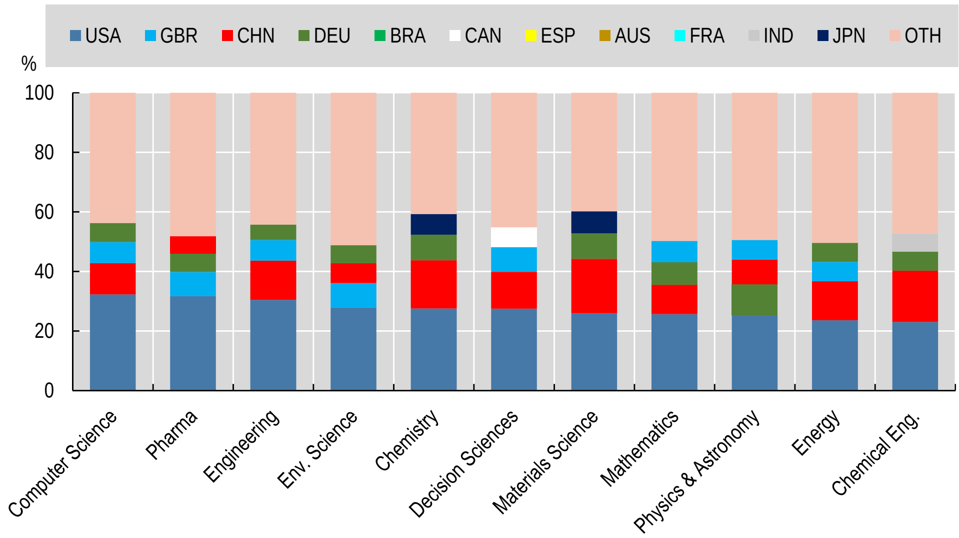

Fig 17. Top 4 countries with the largest number of 10% top-cited publications, by field, 2003-2012[79]

- The trend for China's output of scientific and technical publications also compares favourably with its international peers. Output increased by 400% between 2003 and 2012 and China is the second biggest source of scientific papers after the US. The quality of its publications has improved marginally by less than 2% in terms of percentage of most cited output published during the period; the quality of Chinese scientific paper is comparable to that of Japan (fig 18).

[79] OECD. (2015). Highlights of the OECD Science, Technology and Industry Scoreboard 2015. *Compedium of Bibliometric Science Indicators 2014*. Retrieved from http://www.oecd.org/sti/Science-brief-scoreboard.pdf.

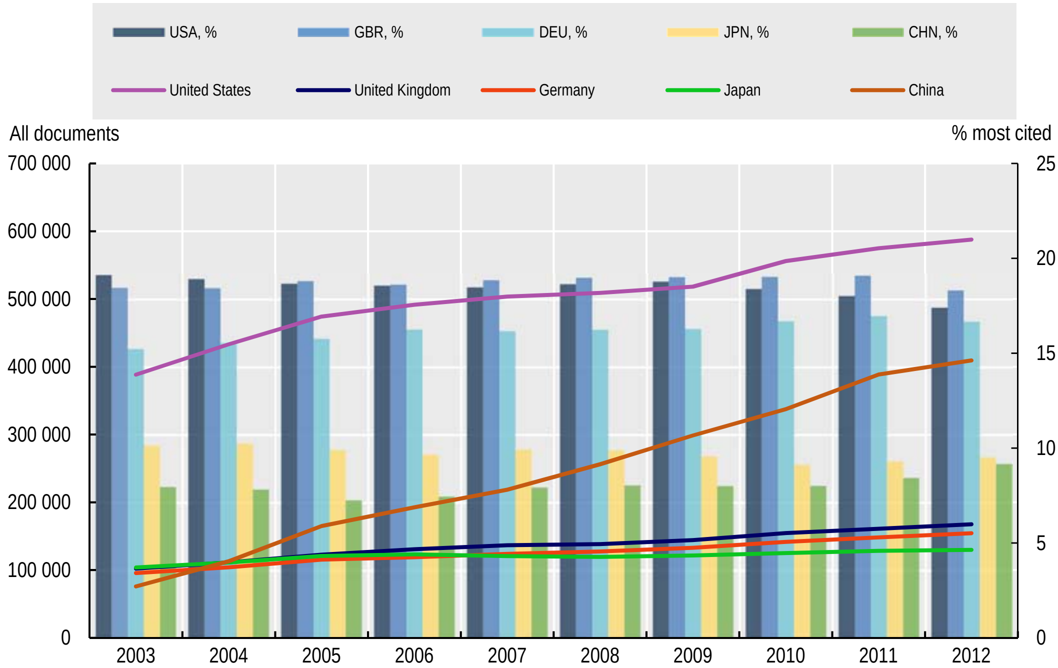

Fig 18. Number of science articles published and more often cited[80]

Entrepreneurial spirit:

- A common measure of entrepreneurial spirit is the formation of new businesses. China has compared favourably with other countries in this respect.

[80] OECD and SCImago Research Group. (2015). Trends in scientific publication output and excellence, selected countries, 2003-2012: number of documents and share among 10% most cited, by author affiliation, whole counts. *Compedium of Bibliometric Science Indicators 2014*. Retrieved from http://oe.cd/scientometrics.

#	Country	Number of New Businesses 2010	Number of New Businesses 2014	% Change
1	China	811,100	1,609,700	98
2	United Kingdom	385,741	581,173	51
3	India	67,509	98,437	46
4	Italy	57,253	83,000	45
-	**BRIC average**	**-**	**-**	**42**
5	Australia	157,667	223,013	41
6	Germany	417,644	585,700	40
7	France	119,319	165,725	39
-	**G7 average**			**31**
8	United States	505,473	561,488	11
9	Japan	99,616	106,644	7

Fig 19. Number of start-ups from 2010 to 2014 for selected countries[81]

Corporate entrepreneurship:

- China started its annual announcement of the top 500 corporations in China in 2004. Comparing the sales figure of its top 500 manufacturers in 2014 to that of 2004, the smallest top 500 manufacturers' sales went from RMB 2.02 billion (USD 240 million) to RMB 6.82 billion (USD 1060 million). Among the more dynamic top 500 private corporations, more than 70% of them engage in manufacturing and the smallest top 500 private corporations had 2014 sales of RMB 9.5 billion (USD 1450 million)[82,].

Innovation and execution capacity:

- We use several parameters to analyse a country's innovation and execution capacities at the micro-level using patent data. One of them is that the

[81] UHY. Chinese lead global growth in new start-ups but economic slowdown threatens business creation. Retrieved from http://www.uhy.com/chinese-lead-global-growth-in-new-start-ups-but-economic-slowdown-threatens-business-creation/

[82] China Federation of Business 全国工商联. (2016). 500 Top Private Business in 2015 中国民营企业 500 强. Retrieved from http://www.ce.cn/xwzx/gnxz/201508/22/t20150822_6292464.shtml

business holds more patents than an individual as it has more execution capacity to commercialize the patent. Another is that domestic entities hold more patents than foreign entities. Also the number of patents issued or applied must show an increasing trend.

- Fig 20 below shows the percentage distribution of outstanding invention patents based on State Intellectual Property Office (SIPO) data. The increasing dominance of domestic institutions is clear.

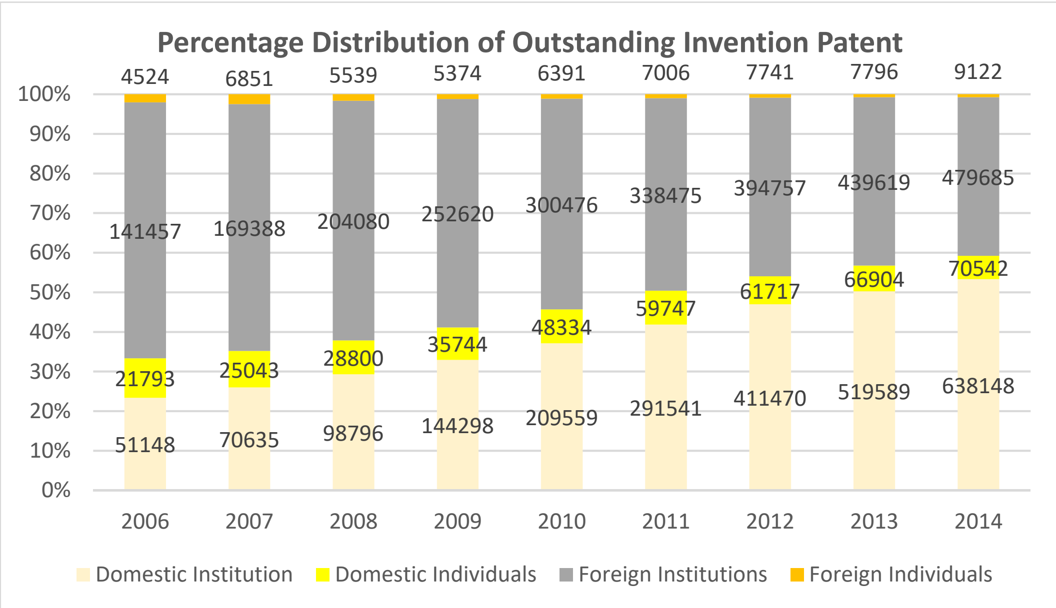

Fig 20. Percentage distribution of outstanding invention patent[83]

- Businesses hold more than 60% of outstanding domestic patents. They are in good position to monetize their inventions as compared to others. China's universities hold a very high percentage of patents that are unique[84].

[83] State Intellectual Property Office 国家知识产权局规划发展司. (2015). China effective patent report 2014 中国有效专利年度报告 2014.

[84] Nelson, R. R. (2008). Why Do Firms Differ & How Does It Matter? A Revisitation. *Seoul Journal of Economics, 21*(4), 607-619.

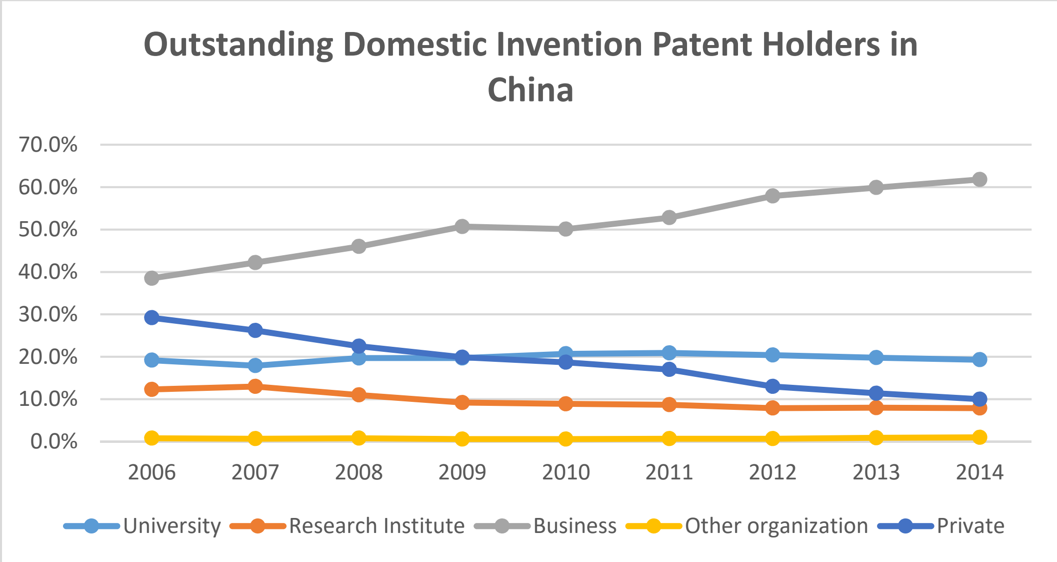

Fig 21. Domestic invention patent holders in China[85]

- We observe the same trend in patent filing as we do for the outstanding patent holding. Locals now file much more patents than foreigners, as shown in fig 22 below.

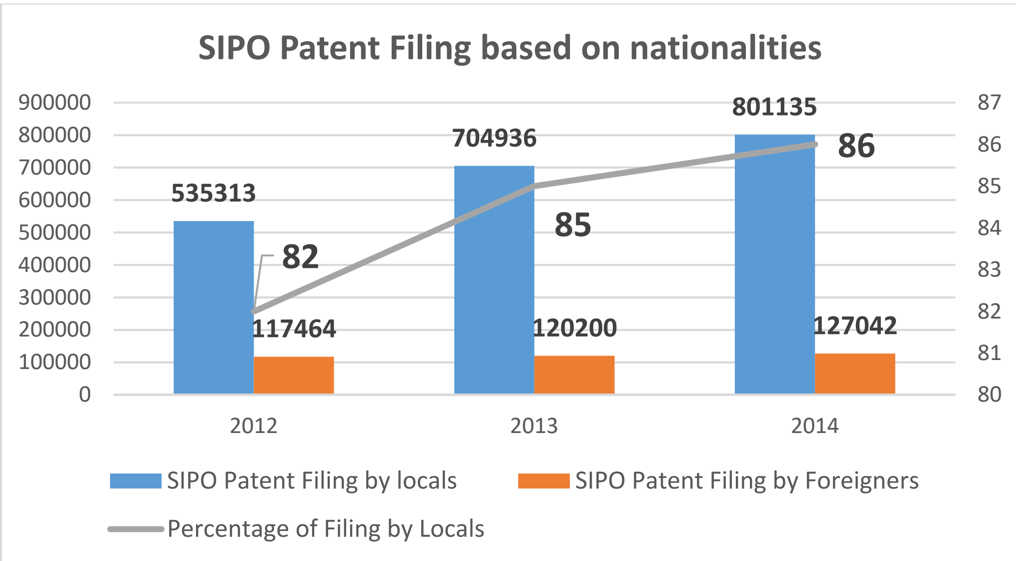

Fig 22. SIPO patent filing based on nationalities[86]

[85] WIPO. Number of outstanding domestic invention patent holders in China, 2000-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

[86] State Intellectual Property Office 国家知识产权局规划发展司. (2015). China effective patent report 2014 中国有效专利年度报告 2014.

- Business is also the most active in patent filing.

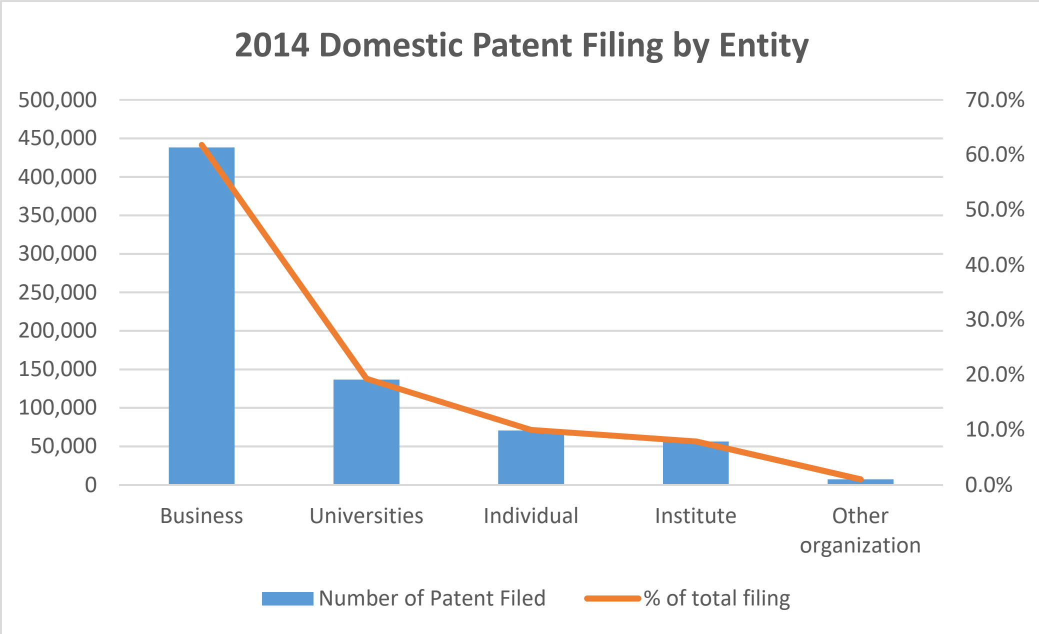

Fig 23. SIPO patent filling based on domestic classification[87]

At the micro-level, instead of relying on home data to prove technological competence, we also used data provided by the World Intellectual Property Organization (WIPO). WIPO provides data for 5 sectors and 35 technical fields.

There is home bias in patent activities for all countries. One way to look at technological leadership is by examining patent filing and publications under WIPO's Patent Cooperation Treaty (PCT). PCT is an international treaty with 148 members that accord *first to file* status in all member countries to patent filers once they file under PCT in their home country. It is agreed that patent files under the PCT are more innovative, creative and have higher commercial value than home-based filings.

[87] State Intellectual Property Office 国家知识产权局规划发展司. (2015). China effective patent report 2014 中国有效专利年度报告 2014.

There are arguments over how representative a patent can be in assessing a firm or country's leadership in certain areas of technologies. Trade secrets or knowhow can usually also accord protection to intelletual property and are not subjected to publication of said technology. However, the proliferation of reverse and forward engineering has made patent filing an increasing attractive option to protect intellectual property rights (IPR). Here, we use PCT data to establish a country's relative technological capacity among nations[88].

- Chinese patent application has dramatically increased since the early 2000s. From 781 patent filings under the PCT in 2000, the country filed 29817 cases in 2015, a growth by 38 times in 16 years. It is now the third largest filer of patents under the PCT. Base on filing data, it filed 13.7% of all patent application in 2015 compared to the traditional leaders, the US's 26.3% and Japan's 20.3%[89].

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[88] Odagari, H., Akira, G., Atsushi, S., & Nelson, R. (2010). *Intellectual Property Rights, Development, and Catch Up: An International Comparative Study*. Oxford University Press.

[89] WIPO. Who filed the Most PCT patents applications in 2015? (2016, March). Retrieved from http://www.wipo.int/export/sites/www/ipstats/en/docs/infographics_systems_2015.pdf

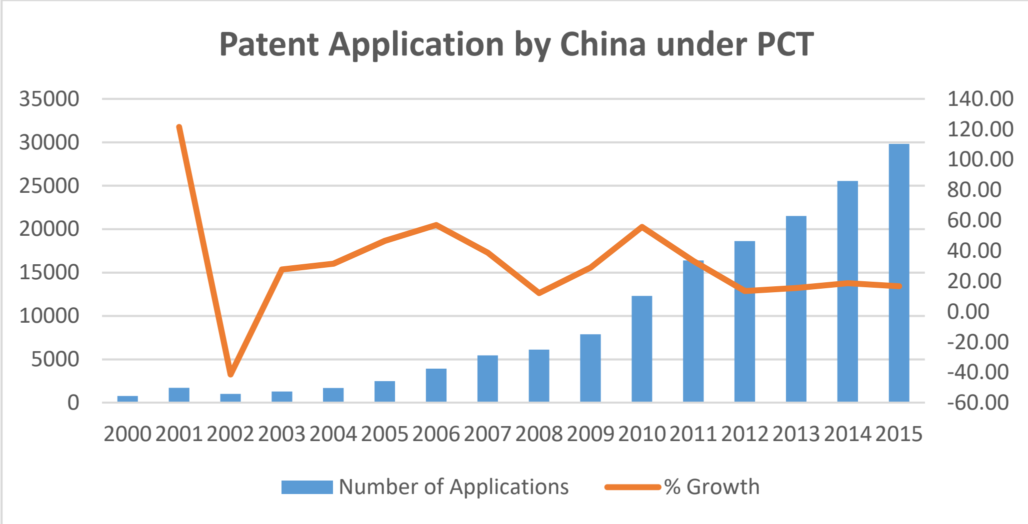


Fig 24. Patent application by China under PCT[90]

- The trend based on the number of PCT publications also confirms the growing influence of China on international patents. In 2011, China published 7.25% of all PCT patents and in 2015, this figure grew to 11.5%. The closer the ratio between filing and publication is, the more confident the applicant is in its technology.

[90] WIPO. Number of PCT applications by filling date in China, 2000-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

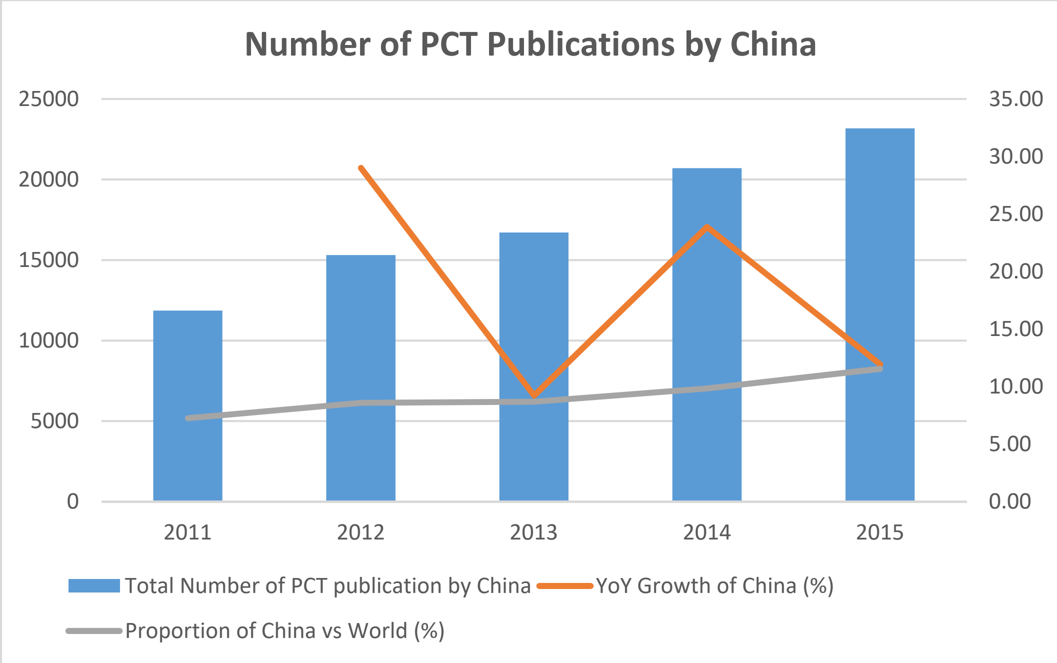


Fig 25. Number of PCT publication by China[91]

- PCT patent filing falls under 5 technological sectors and 35 technical fields. They are as follows:
  - Electrical Engineering (8 technical fields) – Electrical machinery, apparatus and energy, audio visual technology, telecommunications, digital communications, basic communication processes, computer technology, IT methods for management, and semiconductors.
  - Instruments (5 technical fields) – Optics, measurement, analysis of biological materials, control, and medical technology.
  - Chemistry (11 technical fields) – Organic fine chemistry, biotechnology, pharmaceuticals, macromolecular chemistry (polymers), food chemistry, basic materials chemistry, materials (metallurgy), surface

[91] Who filed the Most PCT patents applications in 2015 (2016). Retrieved from http://www.wipo.int/export/sites/www/ipstats/en/docs/infographics_systems_2015.pdf

technology (coating); micro-structural and nanotechnology, chemical engineering, and environmental technology.

- Mechanical Engineering (8 technical fields) – Handling, machine tools; engines (pumps, turbine); textile and paper machines, other special machines, thermal processes and apparatus, mechanical elements, and transport.
- Other Fields (3 technical fields) – Furniture, other consumer goods, and civil engineering.

- Looking at the percentage of total filing for China in a technical field under the PCT can indicate the level of Chinese technology in that particular field. Fig 26 below shows that China is among the strongest players in digital communication and telecommunication. China accounted for more than 20% in each category in 2015. It is a strong player in audio-visual technology and computer technology, with a 15-20% filing share. The only field in which in lags behind under the electrical engineering sector is IT methods for management, where it is below 10%.

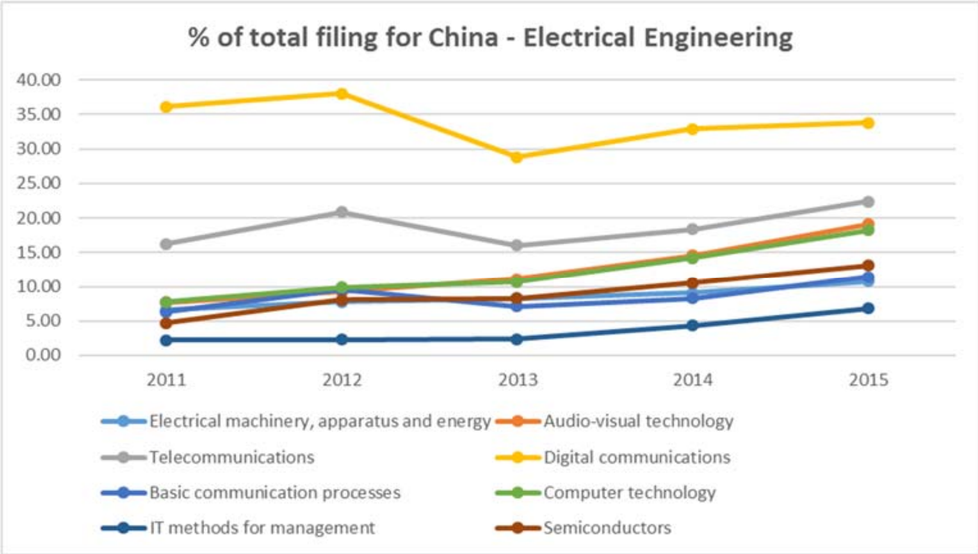


Fig 26. Percentage of total publication in the electrical engineering sector[92]

- As shown in fig 27 below, China is a strong player in optics and still improving. However, it is behind in other technological fields under the instruments sector. Control and mesurement are two fields showing good improvement in the last 4 years.

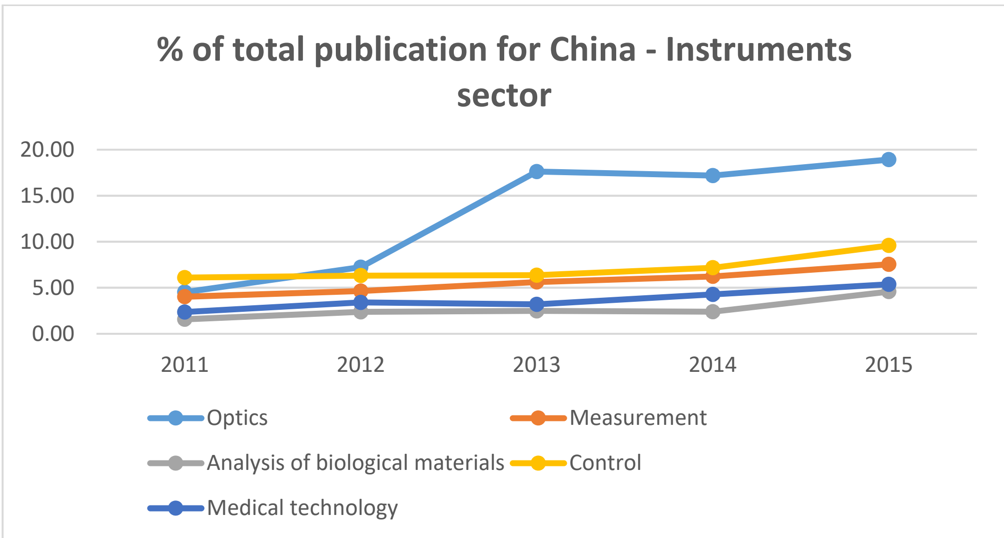


Fig 27. Percentage of total publication in the instruments sector[93]

[92] WIPO. Percentage of total publication in China's electrical engineering sector, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.
[93] WIPO. Percentage of total publication in China's instruments sector, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

- China has shown consistent improvement since 2011 in the number of PCT publications in the first five fields of Chemistry. However, it started from a low base and remains behind in the 5 technological fields (fig 28).

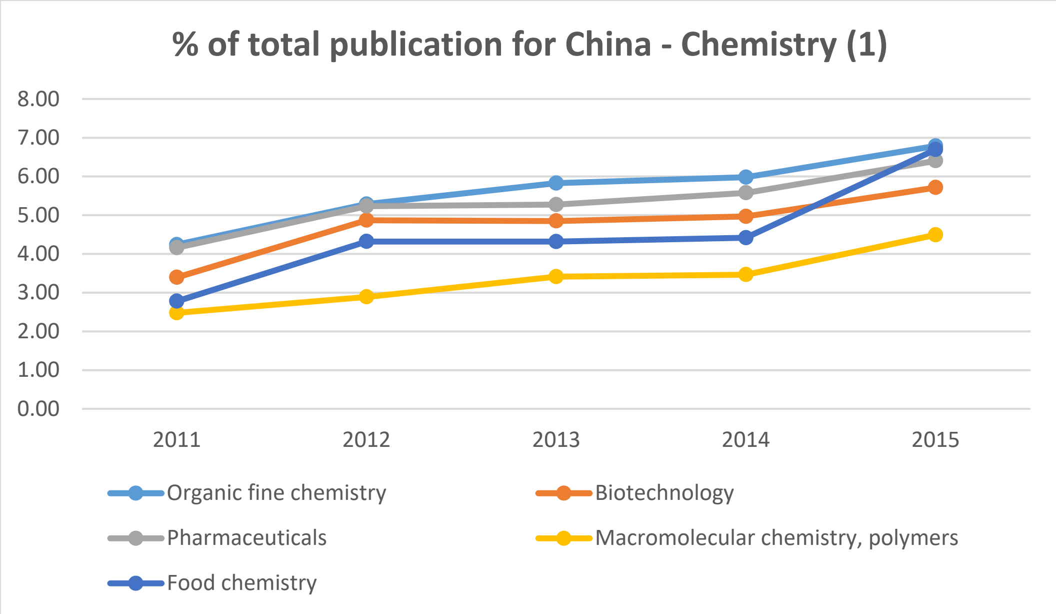


Fig 28. Percentage of total publication in the chemistry sector (part I)[94]

- With reference to fig 29, China has shown consistent improvement since 2011 in the number of PCT publications in the remaining six fields under Chemistry. However, it started from a low base and remains behind in the 6 technological fields.

[94] WIPO. Percentage of total publication in China's chemistry sector, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

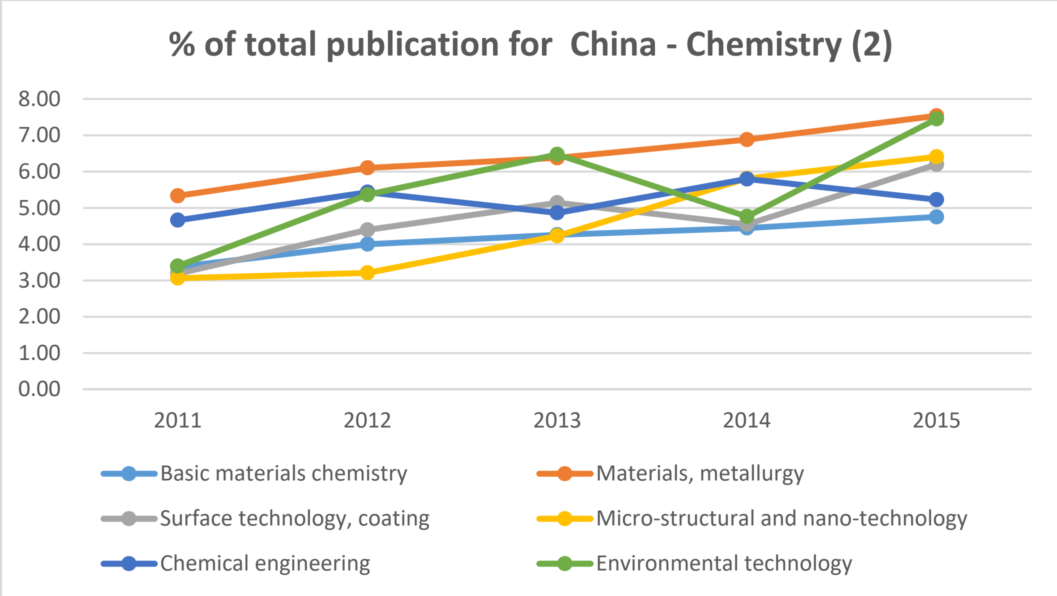


Fig 29. Percentage of total publications in the chemistry sector (part II)[95]

- In the mechanical engineering sector, China has shown consistent improvement, particularly in thermal process and apparatus, which crossed the 10% mark.Its momentum looks good. However, in other areas, it lags behind (fig 30).

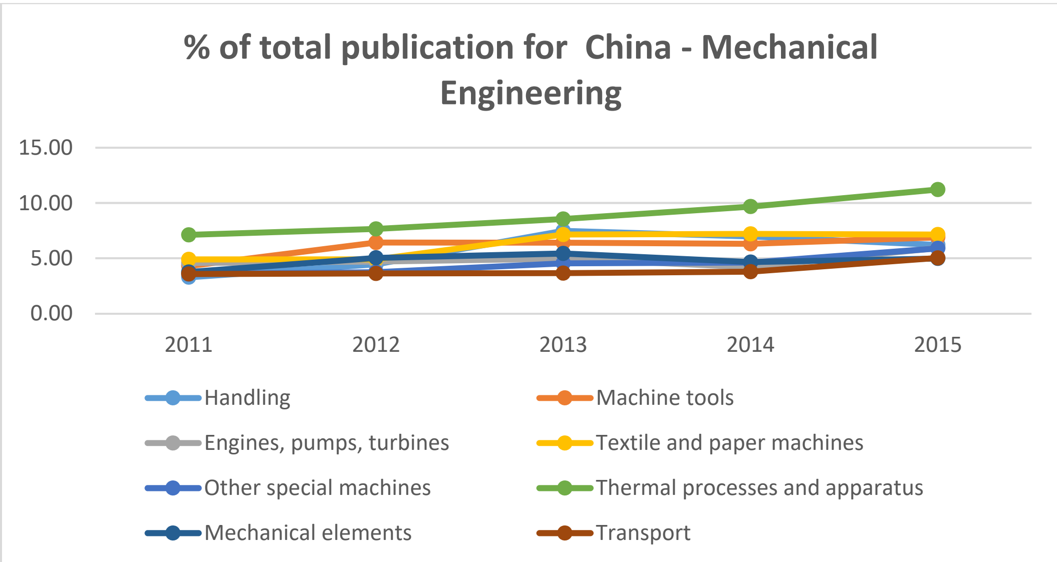


Fig 30. Percentage of total publications in the mechanical enginnering industry[96]

[95] WIPO. Percentage of total publication in China's chemistry sector, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

[96] WIPO. Percentage of total publication in China's mechanical engineering sector, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

- China is apparently strong in furnitures, games and other consumer goods. However, they are not related to the industries under *Made in China 2025* (fig 31).

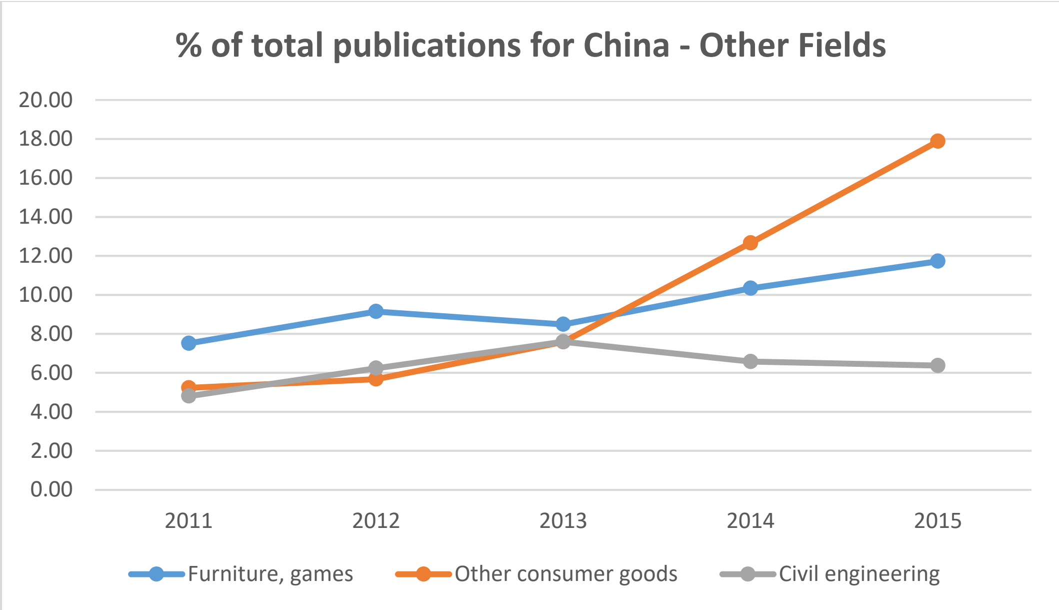


Fig 31. Percentage of total publications in other fields[97]

- If we remove the 3 technological fields that are not related to *Made in China 2025*, China should not encounter technological problems in achieving its goal in industries related to digital communication and telecommunication. They should also have a good chance in computer technology, audio-visual technology and optics.
- China's catch-up dilemma is concentrated in chemistry, mechanical engineering and other areas of instruments. They generally score in the 4-10% area and obviously more effort is needed if China wants to catch up. However, looking at the technologicals target set in *Made in China 2025*, China had set low targets and it stands a good chance of achieving them.

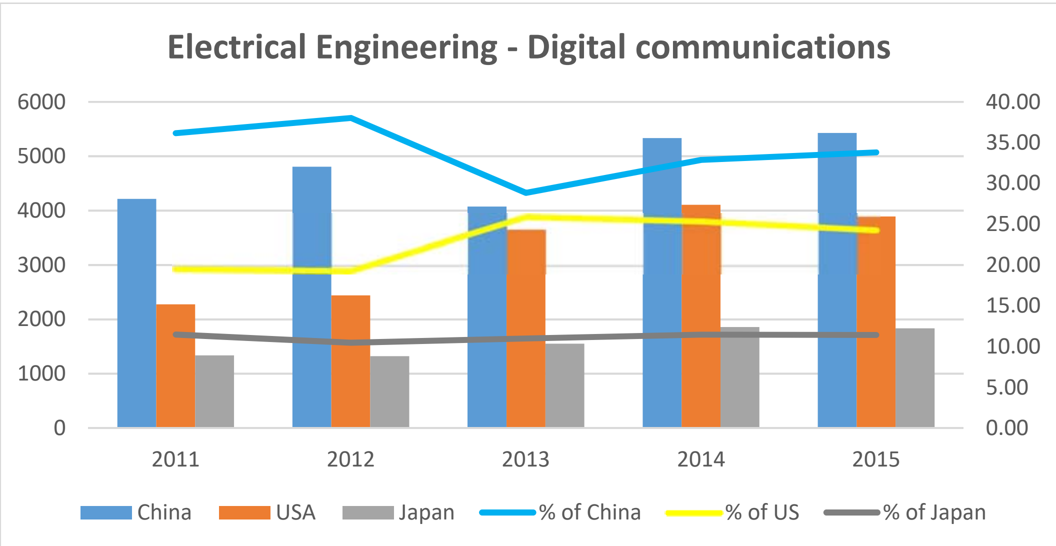
[97] WIPO. Percentage of total publication in other fields, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

- Even in the 4%-5% vicinity for basic materials chemistry (4.75%), macromolecular chemistry - polymer (4.49%), and analysis of biological materials (4.58%), China should possess enough absorptive capacity to learn and advance in the 10 industries targeted under *Made in China 2025* if they are given the technological (learning) opportunities.

Comparison with global peers on patent activities:

We review the global technological distance between China and the other countries by looking at the three top PCT patent publishing countries in each of the 35 categories under PCT. Three countries – US, Japan and China accounted for 60% of PCT filing and they are also the top three in almost all of the categories. We classified the findings as follows:

- China is the leading country in one category- Electrical Engineering-Digital Communication.

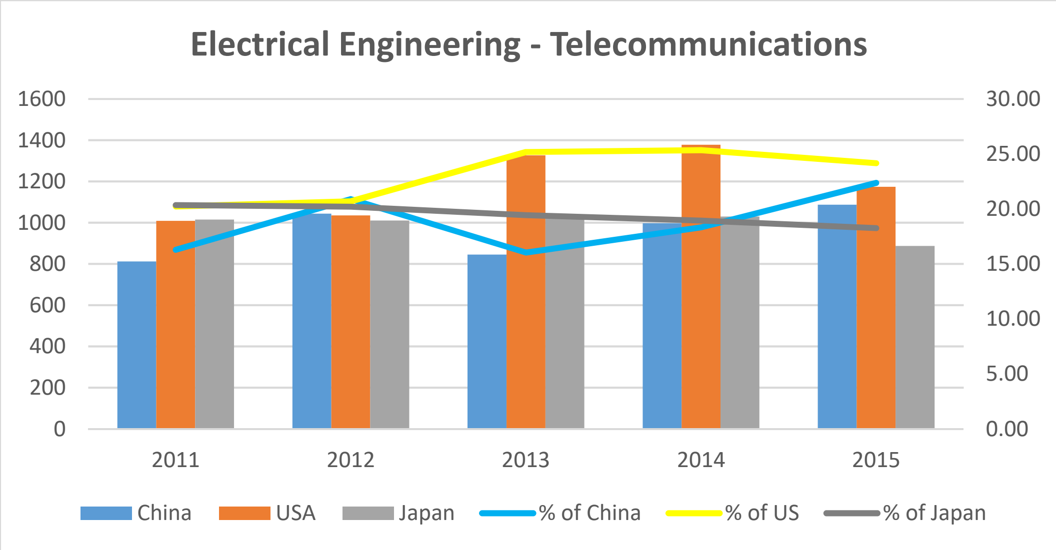


Source: Author compilation based on WIPO data[98]

Fig 32. PCT registration cases and percentage of top three countries – Electrical Engineering -Digital communications

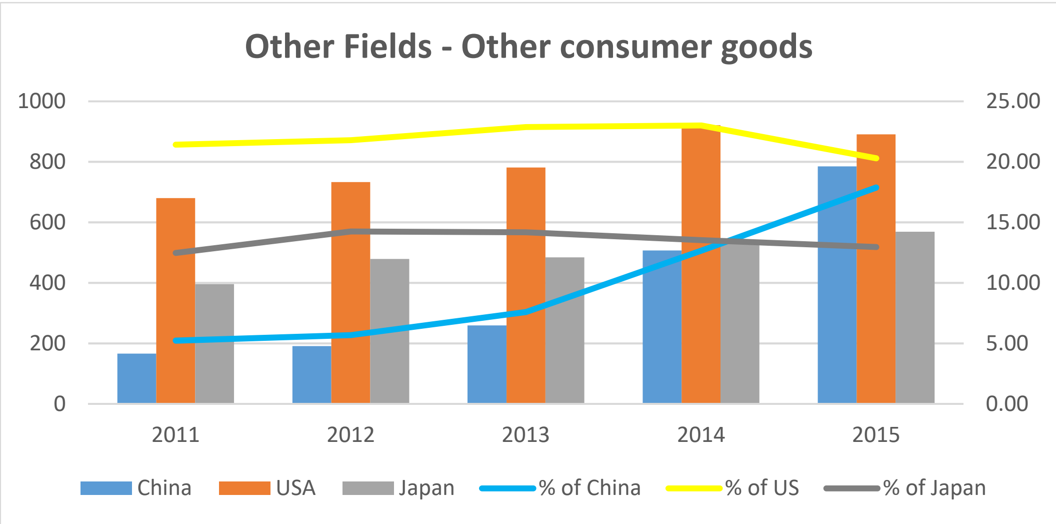
[98] WIPO. Percentage of total publication in other fields, 2011-2015. Retrieved from http://ipstats.wipo.int/ipstatv2/searchForm.

- China ranks second in PCT publications in two categories and it is close to global frontier in these two categories: Electrical Engineering-Telecommunication; Other Fields - Other Consumer Goods.



Source: Author compilation based on WIPO data [99]

Fig 33. PCT registration cases and percentage of top three countries-Electrical Engineering -Telecommunciations



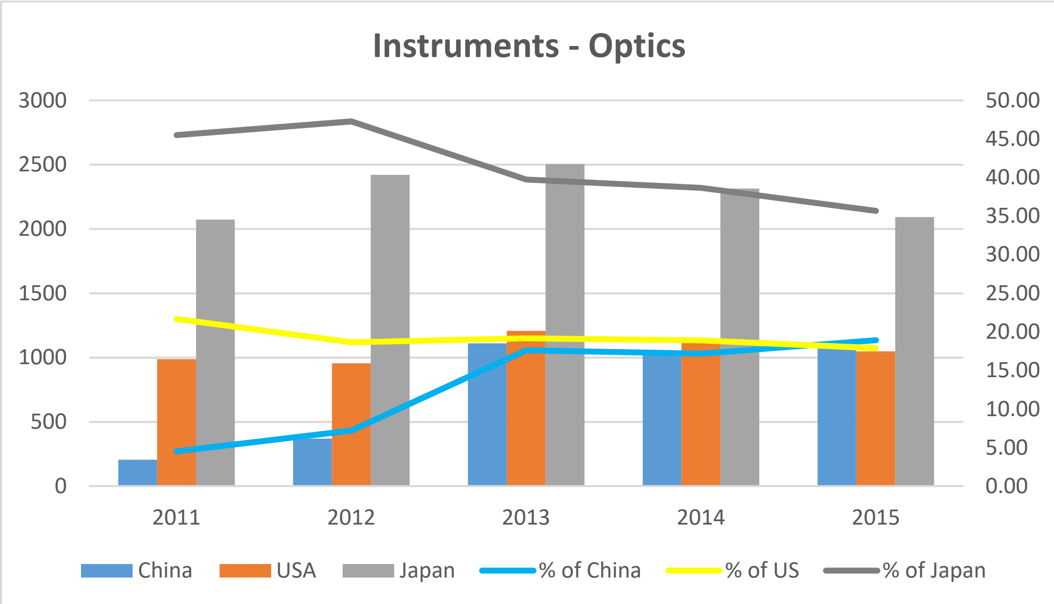
Source: Author compilation bsed on WIPO data[100]

Fig 34. PCT registration cases and percentage of top three countries-Other Fields - Other consumer goods

[99] Ibid.

[100] Ibid.

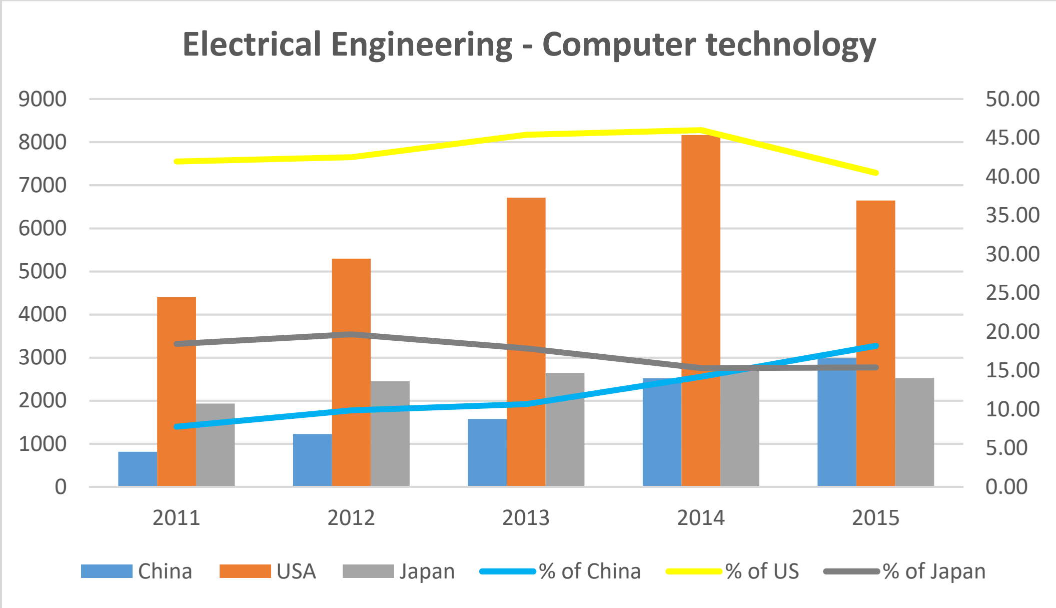
- China ranks second in another two PCT publication categories: Instruments -Optics; Electrical Engineering - Computer Technology. However, if we base the technological distance between two countries by the number of patent publications. The technological distance between number one publishing country, US and China is relatively large.



Source: Author compilation based on WIPO data[101]

Fig 35. PCT registration cases and percentage of top three countries-Instruments – Optics

[101] Ibid.

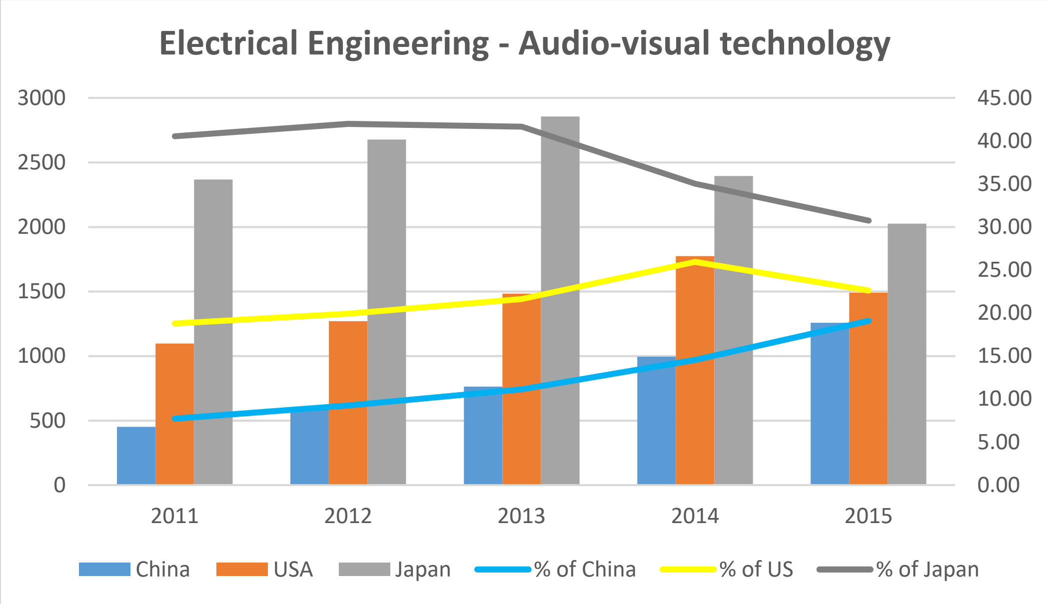


Source: Author compilation based on WIPO data[102]

Fig 36. PCT registration cases and percentage of top three countries-Electrical Engineering- Computer technology

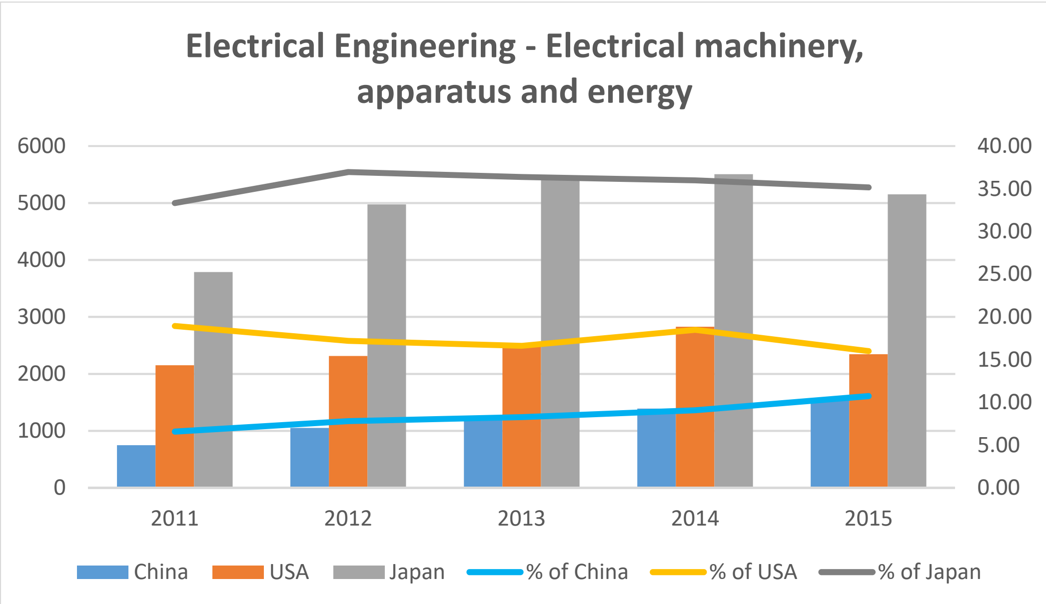
- There are 30 PCT publication categories that China is not in the first two position. Out of the 30 categories, China is catching up to the global leader in the following areas: Electrical Engineering- Audio-Visual Technology; Electrical Engineering- Electrical Machinery, Apparatus and Energy; Electrical Engineering – Basic Communication Process; Instrument-Control; Other Fields- Furniture, Games.

[102] Ibid.



Source: Author compilation based on WIPO data[103]

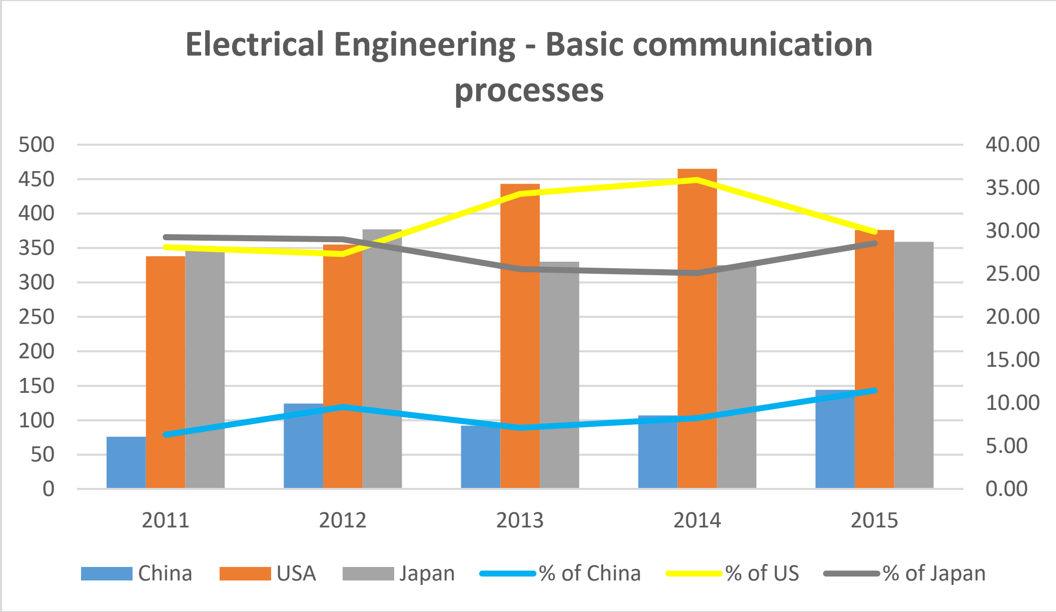
Fig 37. PCT registration cases and percentage of top three countries-Electrical Engineering-Audio-visual technology



Source: Author compilation

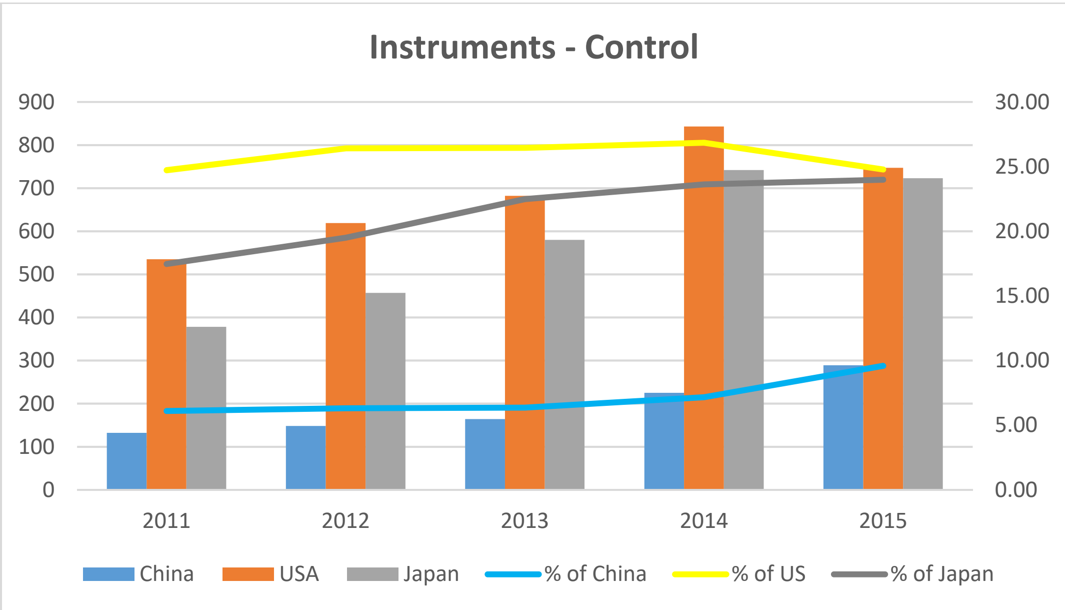
Fig 38. PCT registration cases and percentage of top three countries-Electrical Engineering-Electrical machinery, apparatus and energy

[103] Ibid.



Source: Author compilation based on WIPO[104]

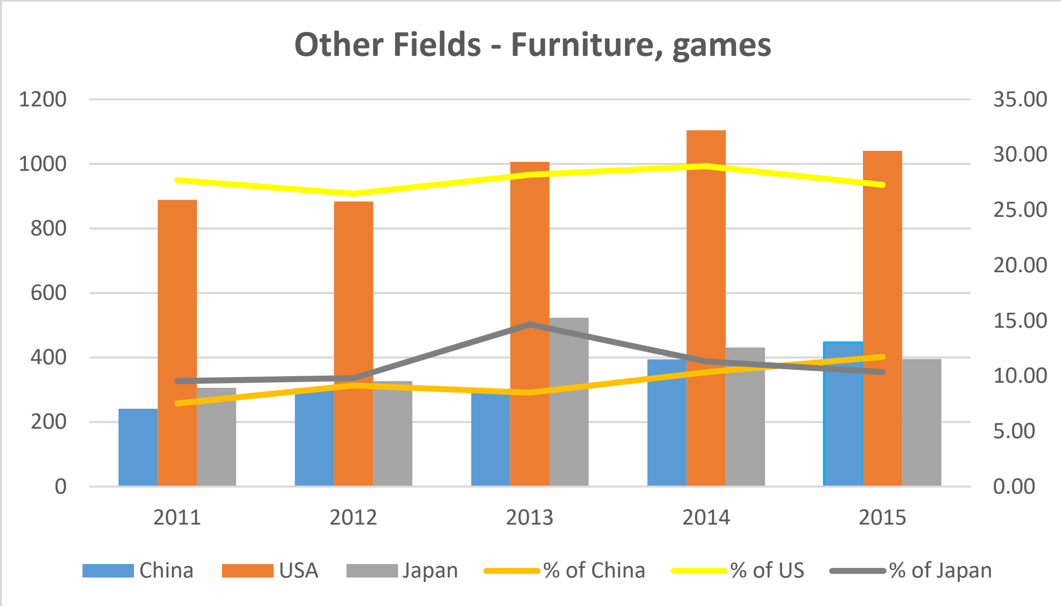
<u>*Fig 39*. PCT registration cases and percentage of top three countries-Electrical Engineering-Basic communication processes</u>



Source: Author compilation based on WIPO[105]

<u>*Fig 40*. PCT registration cases and percentage of top three countries – Instruments - Control</u>

[104] Ibid.
[105] Ibid.

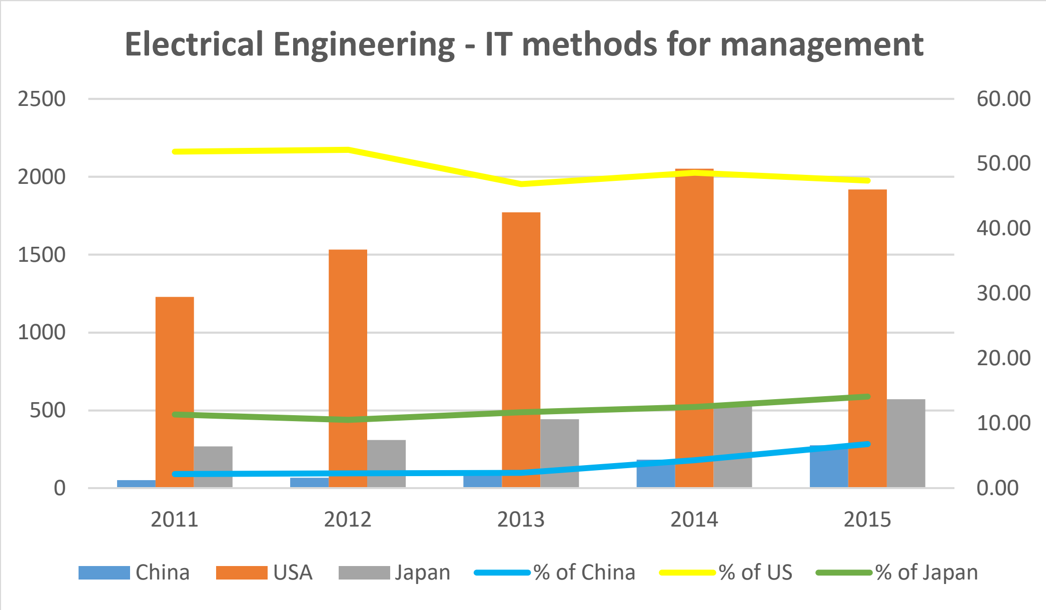


Source: Author compilation based on WIPO[106]

Fig 41. PCT registration cases and percentage of top three countries-Other Fields-Furniture, games

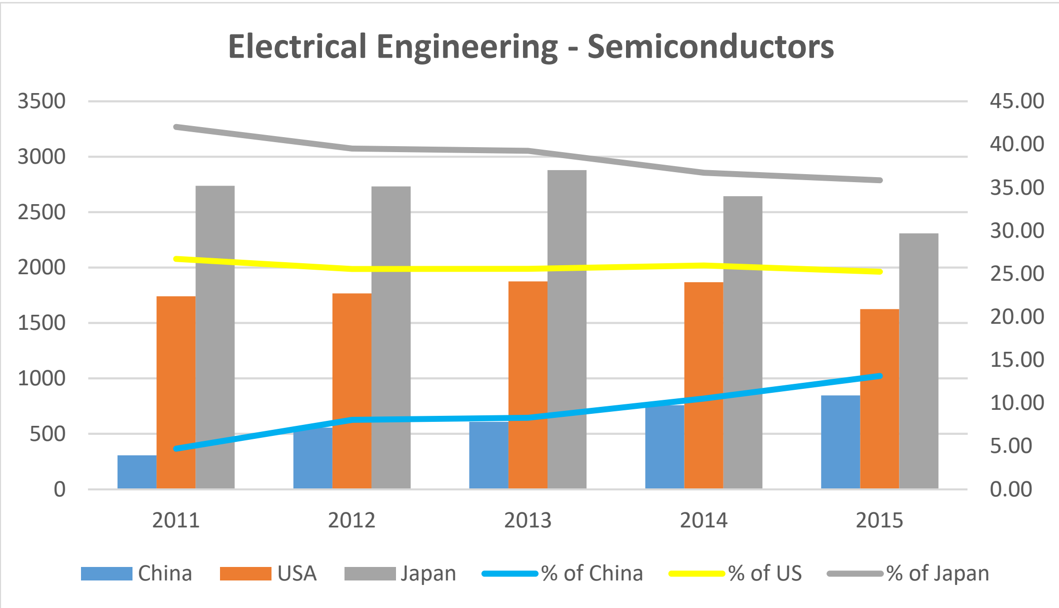
- China is behind in 25 categories based on PCT publications and the technological distance in these areas with the two global leaders are significant:

[106] Ibid.



Source: Author compilation based on WIPO data [107]

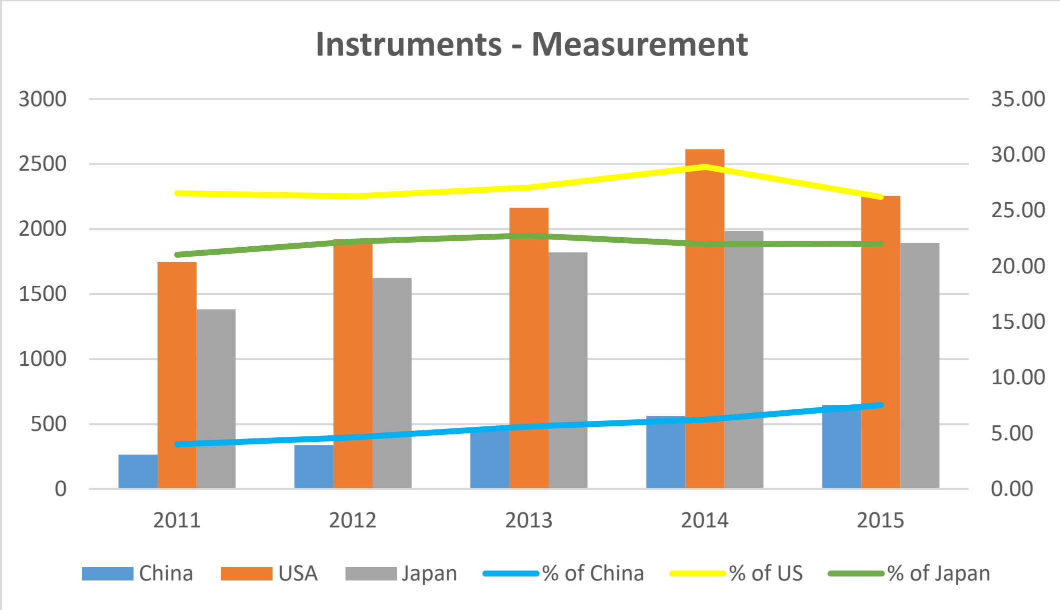
Fig 42. PCT registration cases and percentage of top two countries and China – Electrical Engineering - IT methods for management



Source: Author compilation

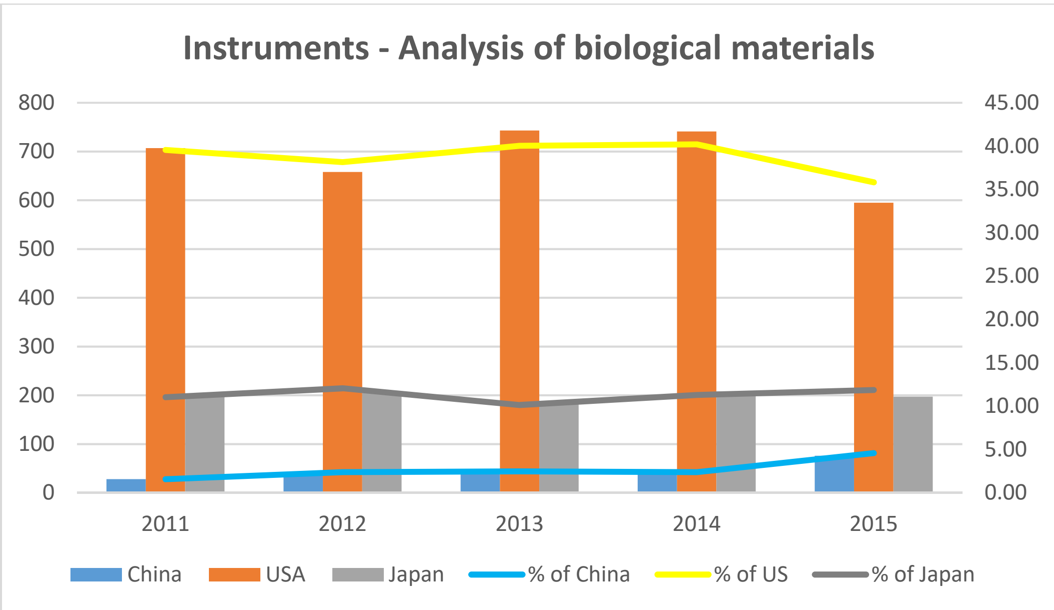
Fig 43. PCT registration cases and percentage of top two countries and China -Electrical Engineering-Semiconductors

[107] Ibid.



Source: Author compilation based on WIPO data[108]

Fig 44. PCT registration cases and percentage of top two countries and China-Instrument- Measurement

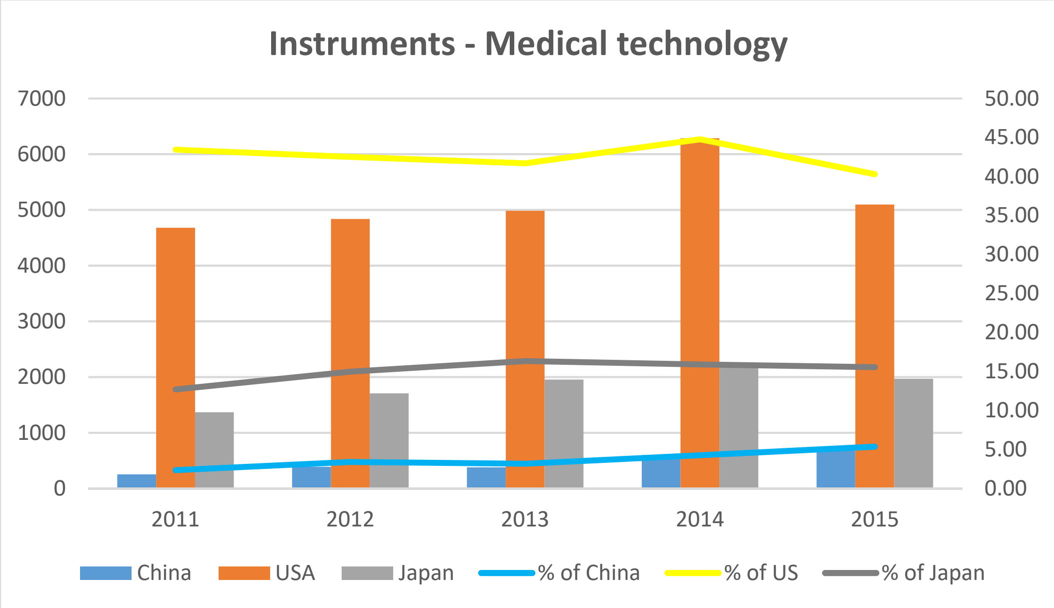


Source: Author compilation based on WIPO data[109]

Fig 45. PCT registration cases and percentage of top two countries and China-Instrument- Analysis of biological materials

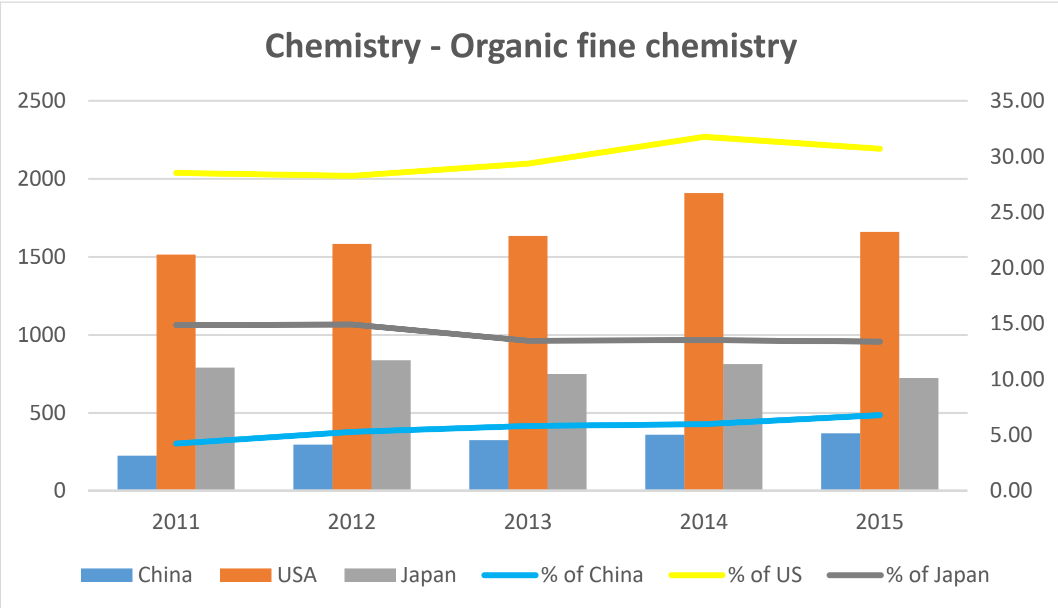
[108] Ibid.

[109] Ibid.



Source: Author compilation based on WIPO data[110]

Fig 46. PCT registration cases and percentage of top two countries and China – Instrument - Medical technology

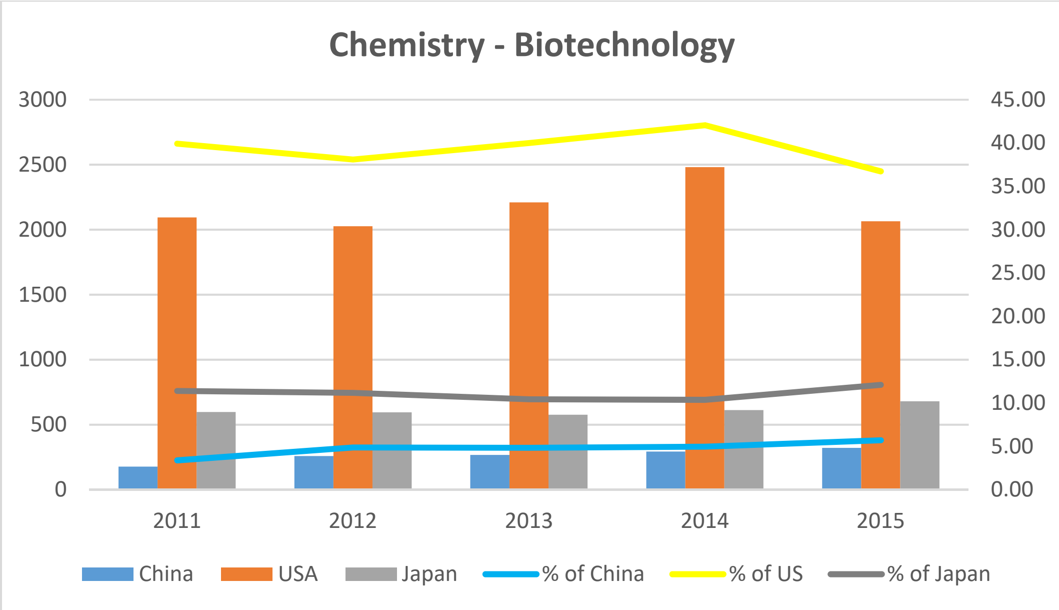


Source: Author compilation based on WIPO data[111]

Fig 47. PCT registration cases and percentage of top two countries and China – Chemistry - Organic fine chemistry

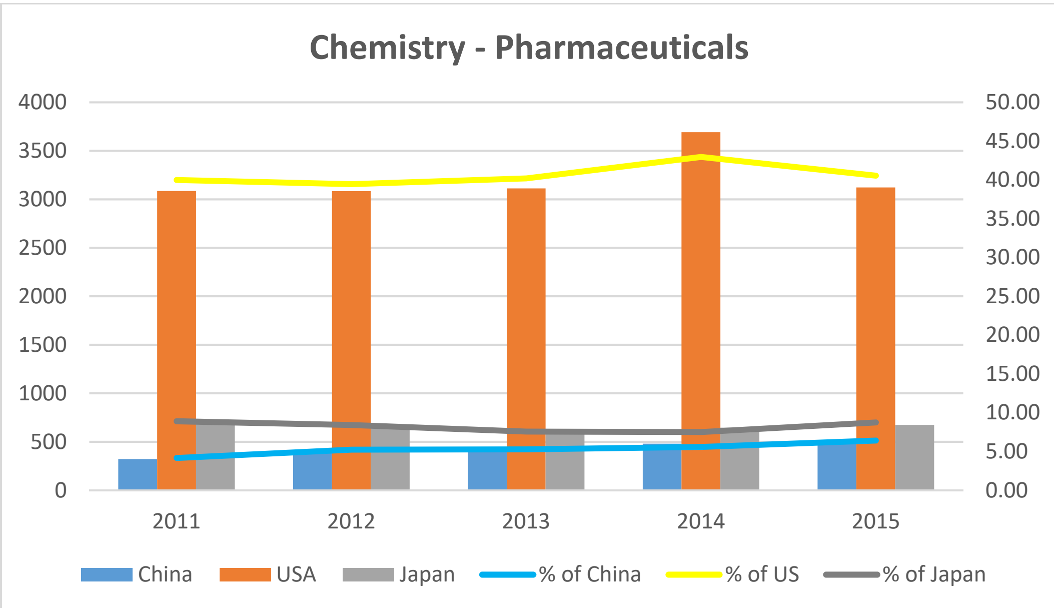
[110] Ibid.

[111] Ibid.



Source: Author compilation based on WIPO data[112]

Fig 48. PCT registration cases and percentage of top two countries and China – Chemistry - Biotechnology

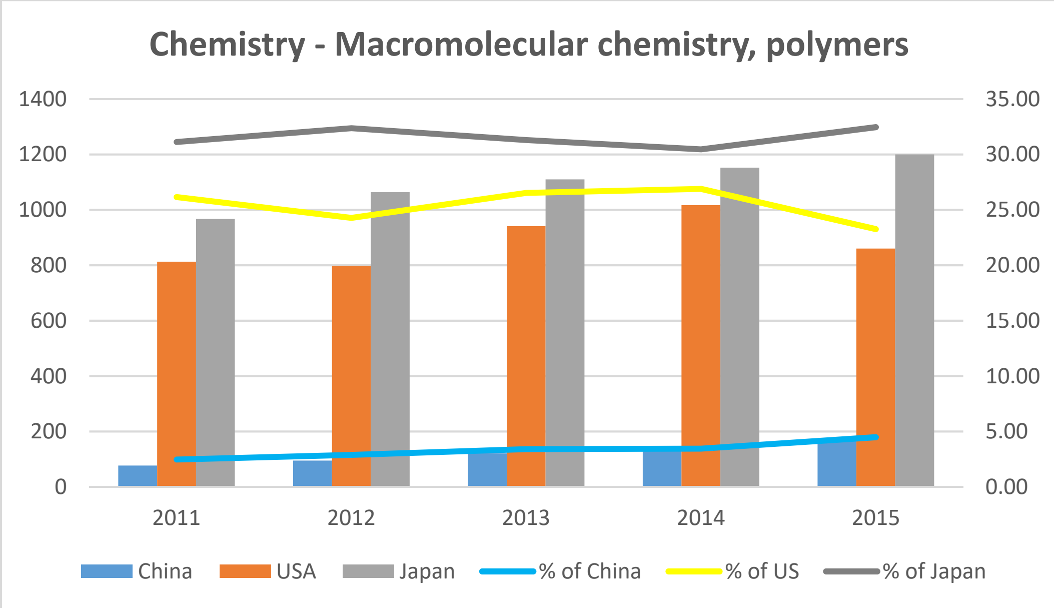


Source: Author compilation based on WIPO data[113]

Fig 49. PCT registration cases and percentage of top two countries and China – Chemistry - Pharmaceuticals

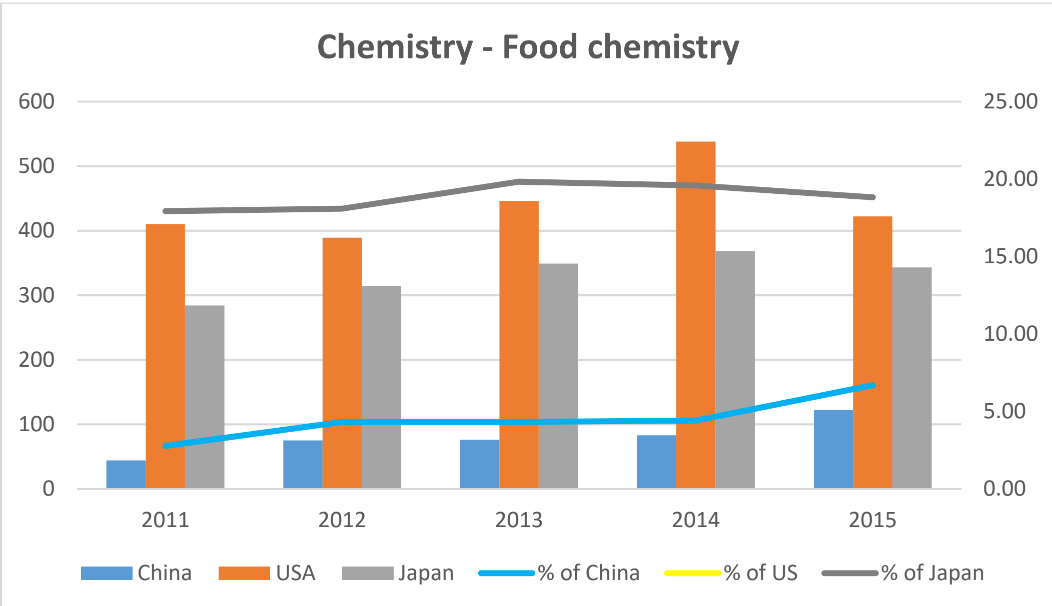
[112] Ibid.

[113] Ibid.



Source: Author compilation based on WIPO data[114]

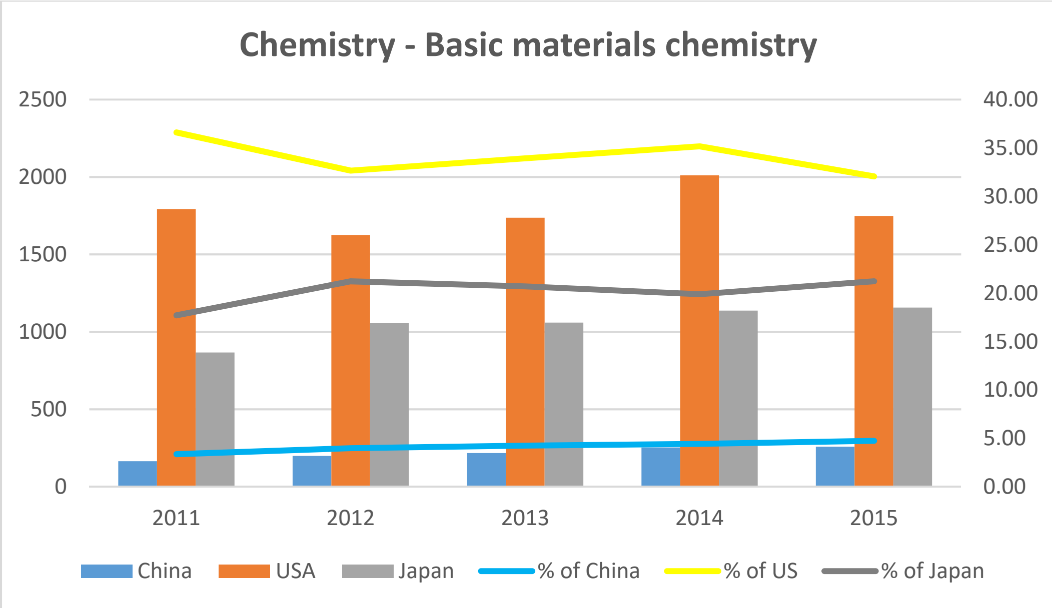
Fig 50. PCT registration cases and percentage of top two countries and China – Chemistry - Macromolecular chemistry, polymers



Source: Author compilation based on WIPO data[115]

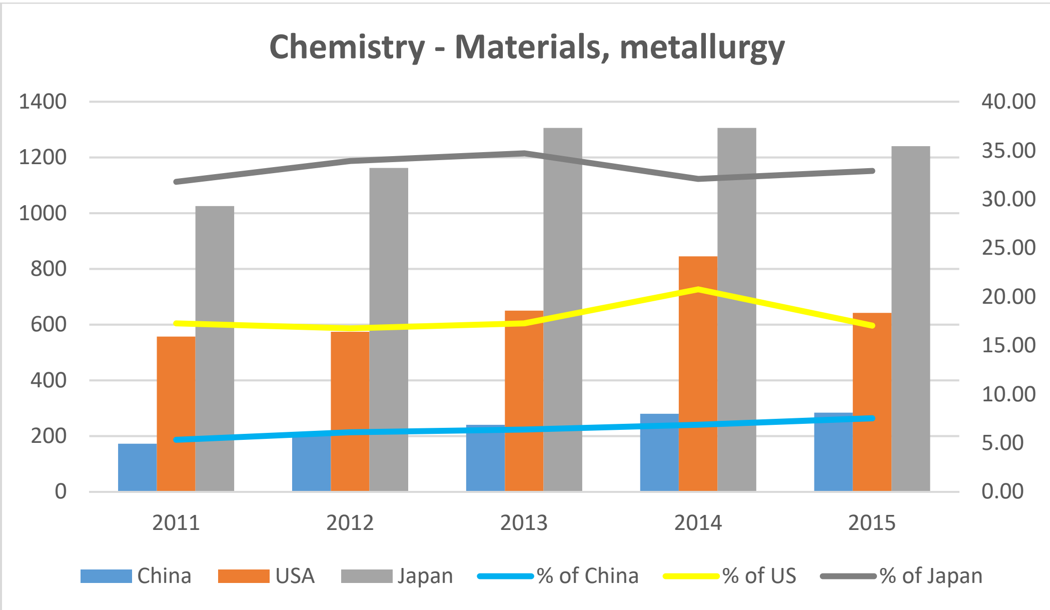
Fig 51. PCT registration cases and percentage of top two countries and China – Chemistry - Food chemistry

[114] Ibid.
[115] Ibid.



Source: Author compilation based on WIPO data[116]

Fig 52. PCT registration cases and percentage of top two countries and China – Chemistry - Basic materials chemistry

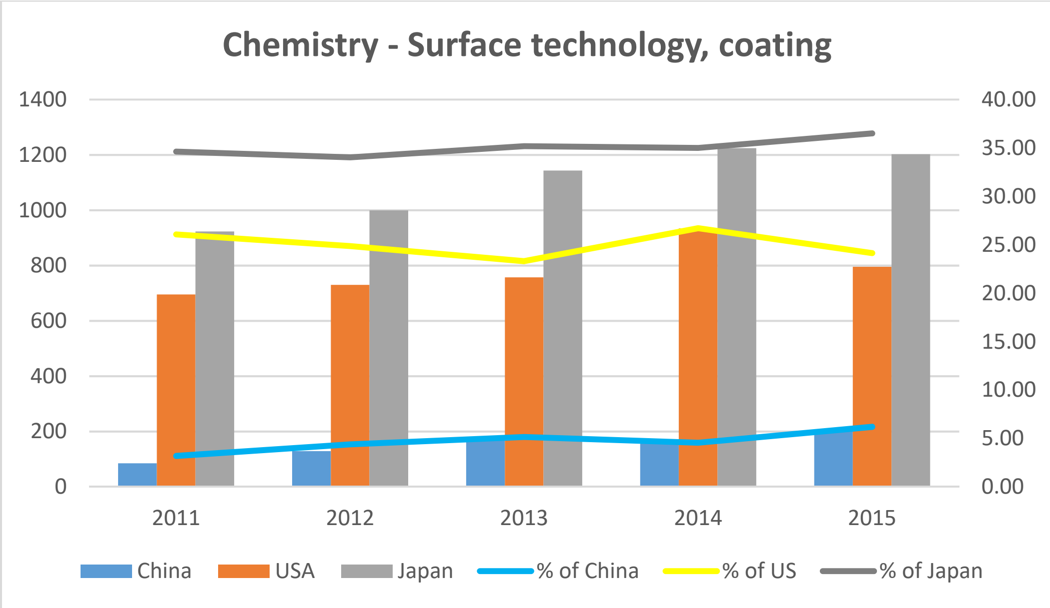


Source: Author compilation based on WIPO data[117]

Fig 53. PCT registration cases and percentage of top two countries and China – Chemistry - Organic fine chemistry

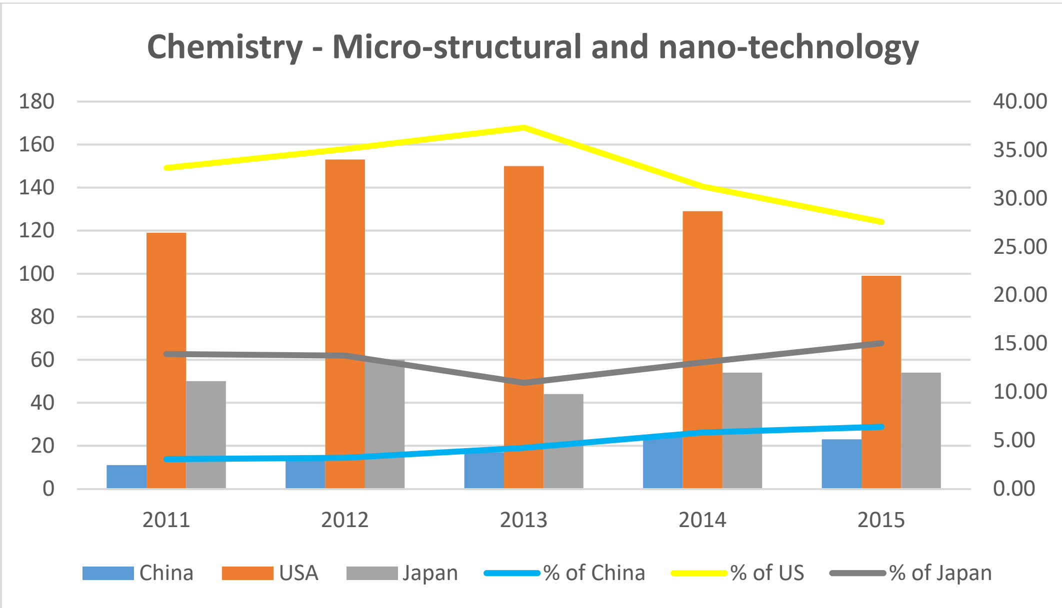
116 Ibid.

117 Ibid.



Source: Author compilation based on WIPO data[118]

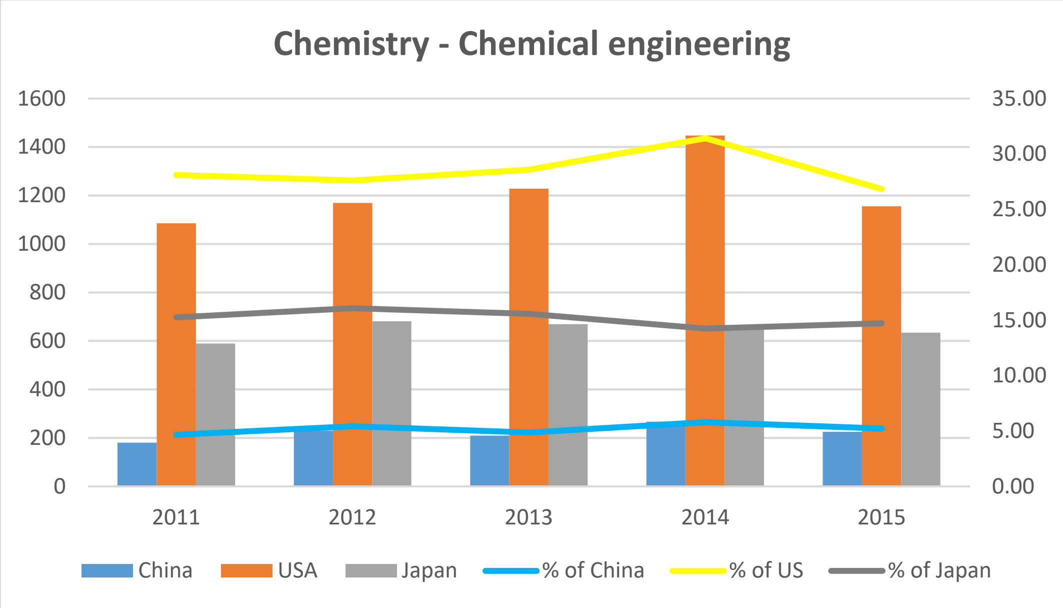
Fig 54. PCT registration cases and percentage of top two countries and China – Chemistry - Surface technology, coating



Source: Author compilation based on WIPO data[119]

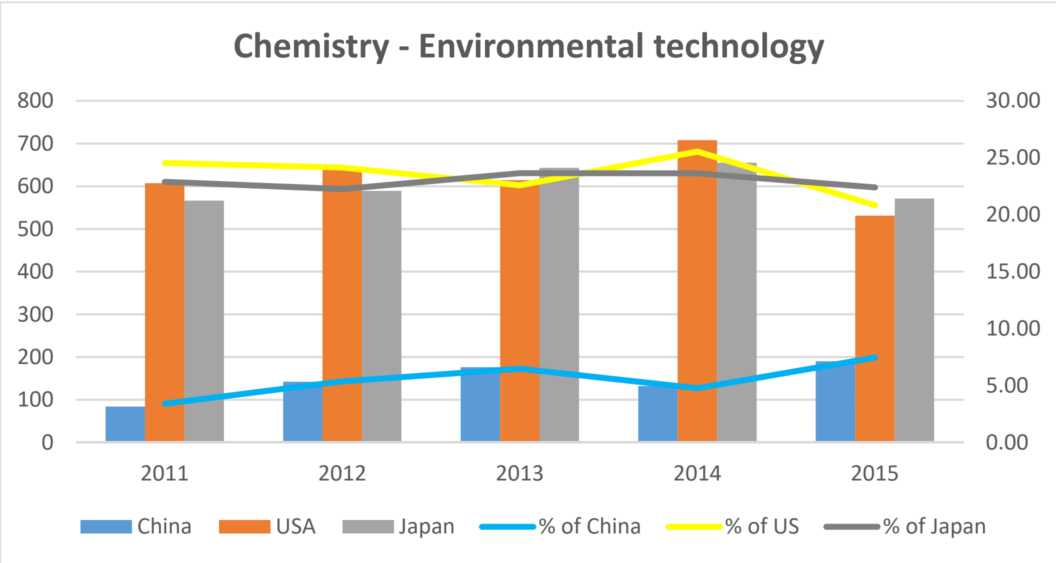
Fig 55. PCT registration cases and percentage of top two countries and China – Chemistry - Micro-structural and nanotechnology

[118] Ibid.
[119] Ibid.



Source: Author compilation based on WIPO data[120]

Fig 56. PCT registration cases and percentage of top two countries and China – Chemistry - Organic fine chemistry

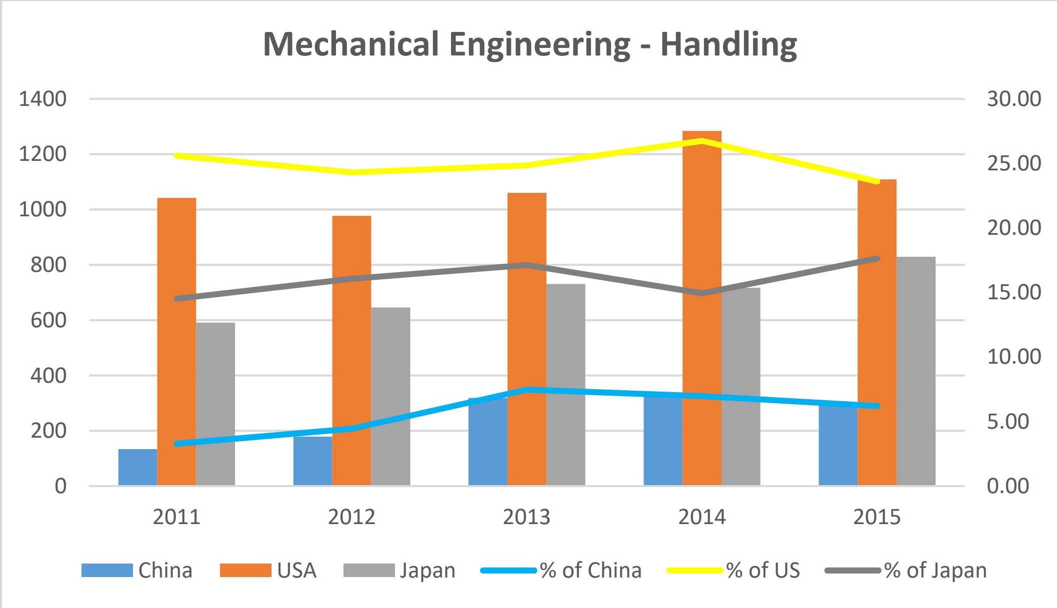


Source: Author compilation based on WIPO data[121]

Fig 57. PCT registration cases and percentage of top two countries and China – Chemistry - Environmental technology

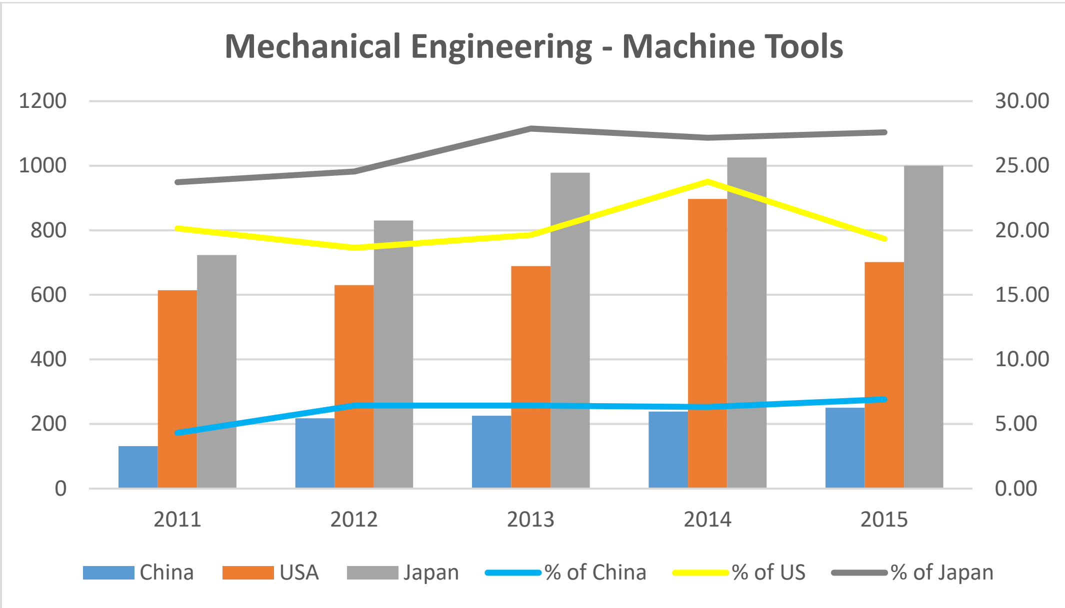
[120] Ibid.

[121] Ibid.



Source: Author compilation based on WIPO data[122]

Fig 58. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Handling

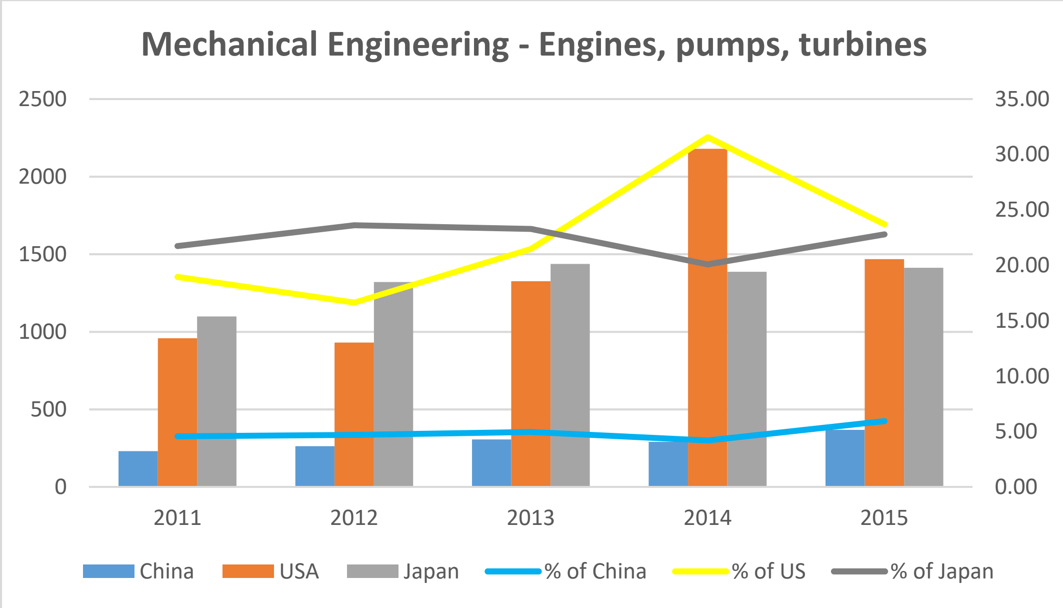


Source: Author compilation based on WIPO data[123]

Fig 59. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Machine tools

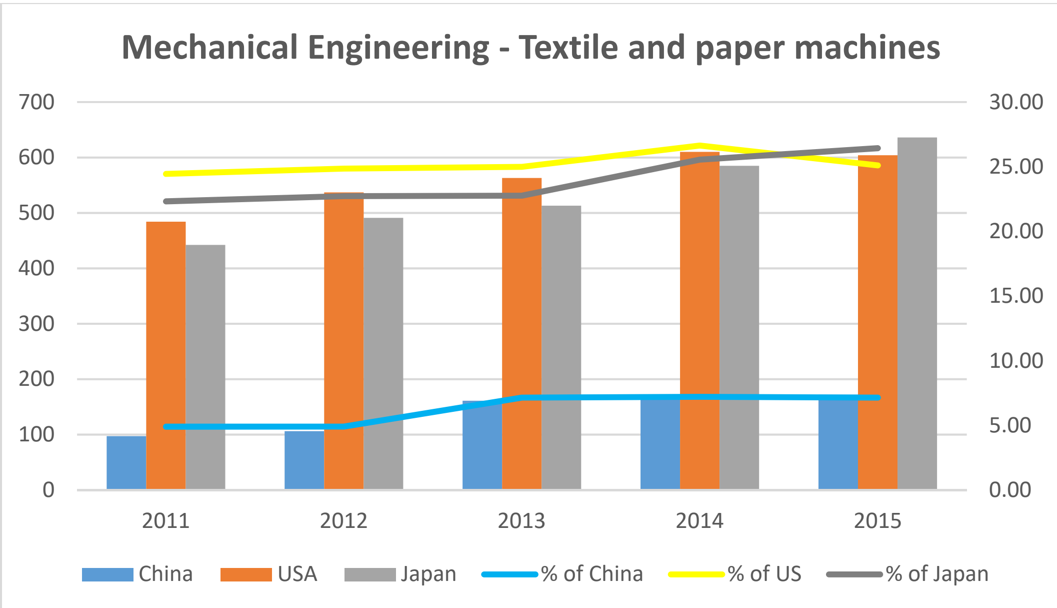
122 Ibid.

123 Ibid.



Source: Author compilation based on WIPO data[124]

Fig 60. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Engines, pumps, turbines

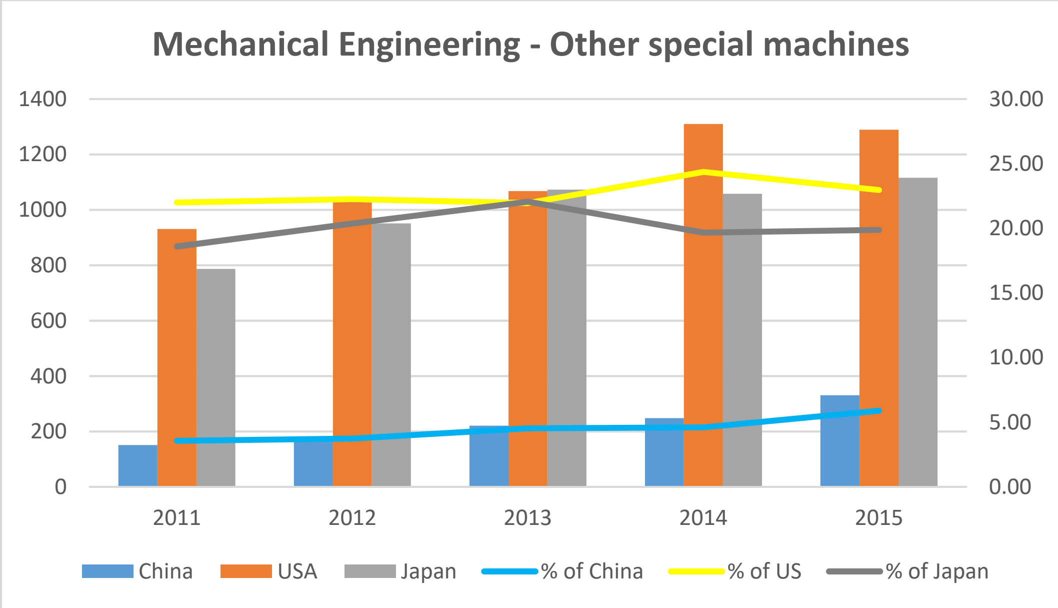


Source: Author compilation based on WIPO data[125]

Fig 61. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Textile and paper machines

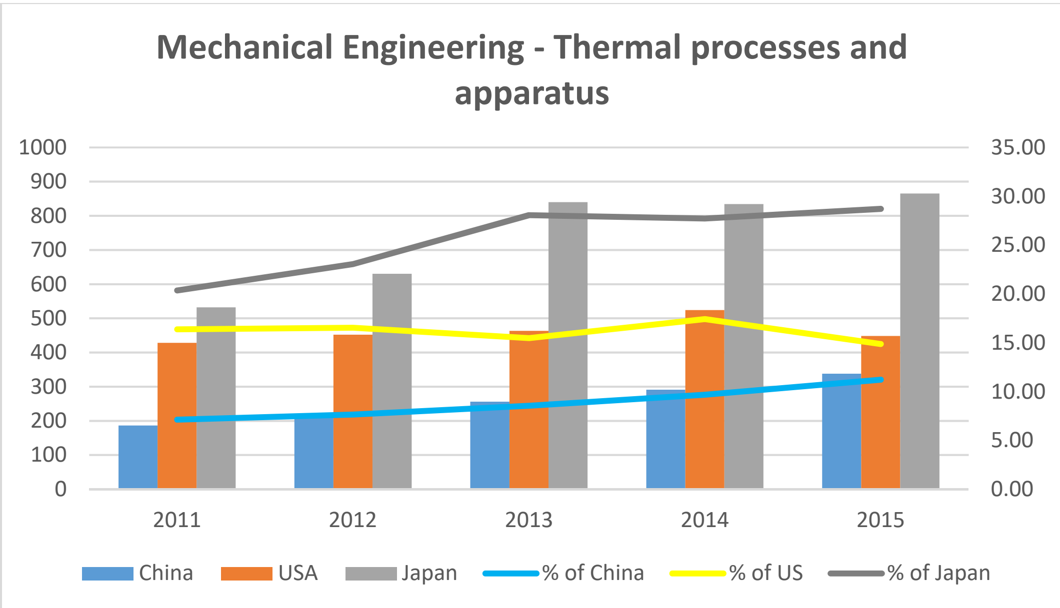
[124] Ibid.

[125] Ibid.



Source: Author compilation based on WIPO data[126]

Fig 62. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Other special machines

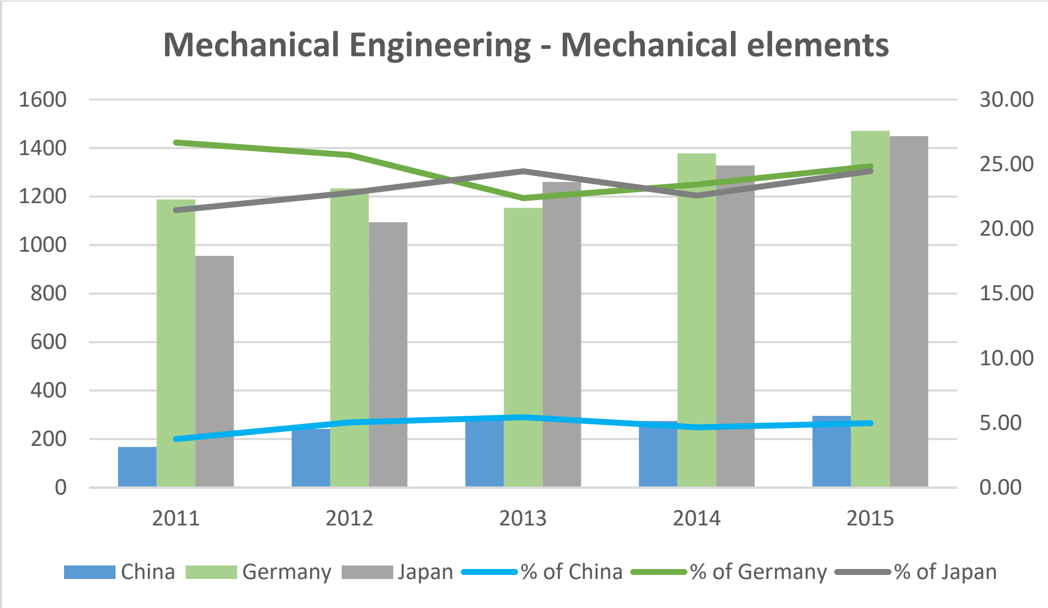


Source: Author compilation based on WIPO data[127]

Fig 63. PCT registration cases and percentage of top two countries and China - Mechanical Engineering – Thermal processes and apparatus

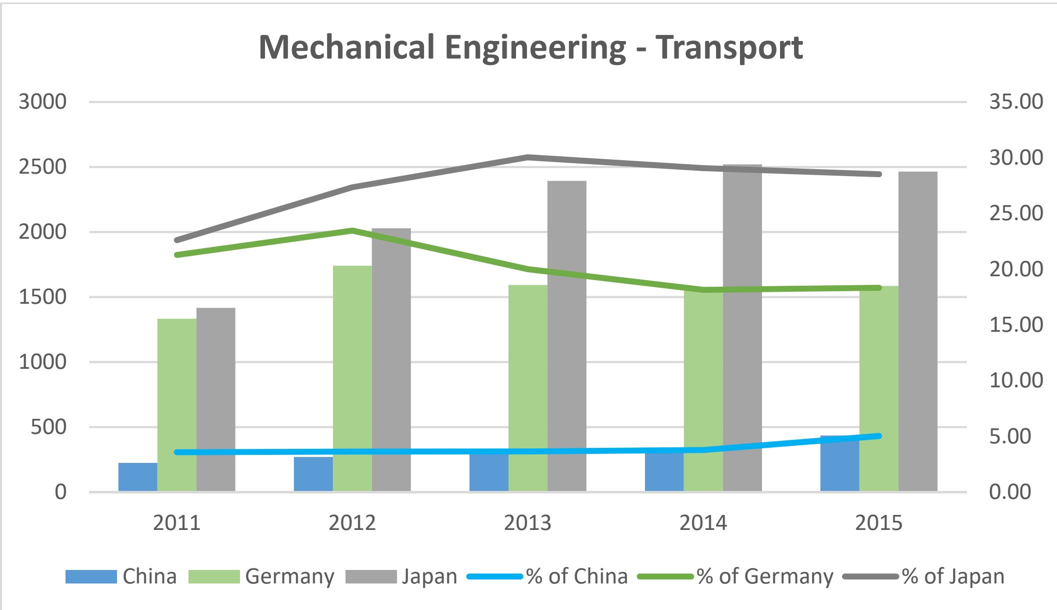
[126] Ibid.

[127] Ibid.



Source: Author compilation based on WIPO[128]

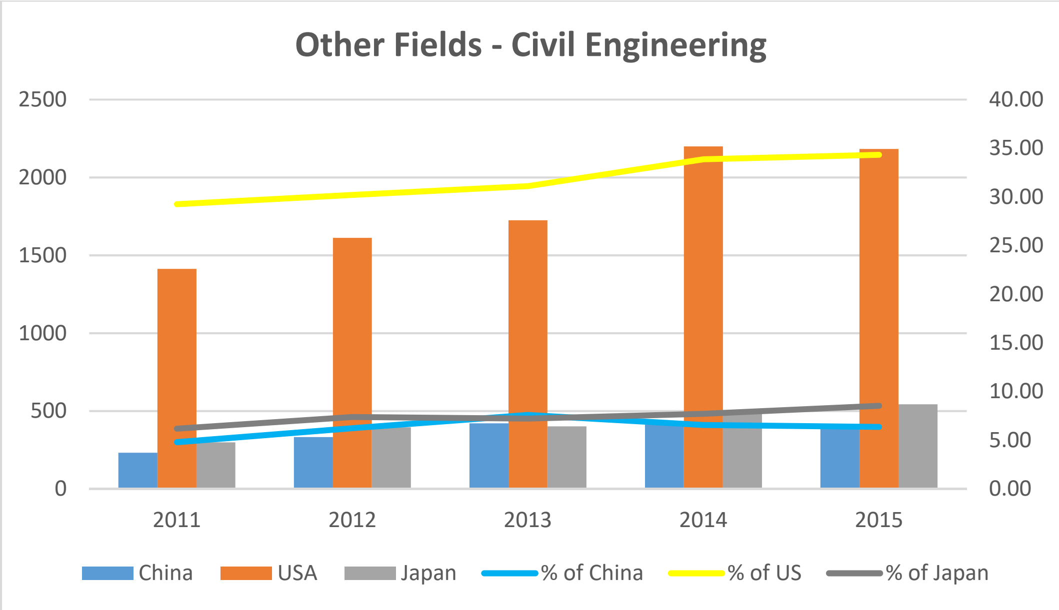
Fig 64. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Mechanical elements



Source: Author compilation based on WIPO data[129]

Fig 65. PCT registration cases and percentage of top two countries and China - Mechanical Engineering - Transport

[128] Ibid.
[129] Ibid.



Source: Author compilation based on WIPO data[130]

Fig 66. PCT registration cases and percentage of top two countries and China - Other Fields – Civil engineering

Chinese PCT publication data revealed two interesting information: Firstly, China in many categories of technologies is still playing a catch-up role. It is the leader in the category of digital comunication, closing in the world leader in four categories and rising fast in five categories to the first two global leaders. However, in the great majority of the remaining 25 categories, Chinese technology distance from the two world leaders are substantial. It is easier for a country to play technology catch-up because the roadmap is already defined by the trailblazer. Secondly, Chinese experience in technolgy catch-up is different from South Korea and Taiwan. The country had developed meaningful patent publications in all 35 categories of technology. Two of the usual constraints in the development of new industries: cumulative technology and general knowledge base are not important in

[130] Ibid.

the case of China. Their scales and breaths in technological foundation provide a good starting point for both technology catch-up and indigenous innovation to build new industries.

Summary of Findings at micro-level:

Our findings indicated that China developed the four elements at the micro-level under neo-Schumpeterian analysis that are necessary pre-conditions for their success in the *Made in China 2025*. The country has built up a growing and increasingly sophisticated human capital base for innovation. The human capital base is turning out to be increasingly high in quality scientific research outputs to serve as theoretical base of innovations. Moreover, more start-up and larger corporations are acting as innovation enabling entrepreneurs by converting these innovations into patents to enhance the innovations' monetization propects. The country is closing the technology gap with the global leader in many areas of technologies as shown by its fast growing international patent publications in all areas of technologies . The country had developed meaningful technology presence in all 35 areas of patent under the international PCT categories of technology. The Chinese technological foundation have therefore both depth and breadth. It has therefore reached a stage where the country can not only embark on meaningful indigenous technological innovations and breakthroughs, but also easily absorb imported technology with the presence of strong foundation .

Chapter 5 - Research Findings at the meso-level of neo-Schumpeterian Analysis

This chapter reports the findings on the approach taken by the Chinese government in developing the high-speed rail industry at the meso-level.

The meso-level or industrial level is the monetization area of innovations. It provides the ecosystem to monetize innovations and drive economic growth. While micro-level successful entrepreneurs or corporations come and go, a successful meso-level industry maintains its innovative power and global leadership for a long period of time. Empirical evidences show that all developed countries sustain their economic dynamism on a few anchor industries. Nurturing high value-added innovative industries is an unwritten economic policy of all developed and aspiring countries.

Introduction to Findings at meso-level:

We use the neo-Schumpeterian framework of technological regime to analyse the challenges a country face in developing a new, higher value-added innovative industry.

In particular, we will be using this framework to analyse China's High Speed Rail (HSR) industry – one of the ten industries under *Made in China 2025* – and find out how China succeeded in developing this industry. A historical evolutionary narrative provides the best perspective to understand the challenges the industry met along its evolution from scratch to the present state, the timeline approach highlights the critical decisions that the authority make to overcome problems along the way. We use three historical time periods to facilitate the investigation:

1. The Chinese HSR industry (before 2004);
2. The acquisition and assimilation of foreign rolling stock technology (2004-2007)
3. The indigenous technological breakthrough and building of the local HSR industry (2008 – present)

The four parameters of technological regime, in the context of the Chinese HSR industry, are as follow:

1. Opportunities (OPP). This refers to how likely it is for China to acquire the necessary technology in the HSR industry, either through indigenous technological breakthrough, or from foreign sources;
2. Appropriability (APP). This refers to the different kinds of reward opportunity the HSR industry has for its participants;
3. Cumulativeness (CUM). This refers to how important earlier accumulated knowledge on rail technology is to current innovation efforts;
4. Knowledge Base (BAS). This refers to the kind of knowledge base needed in current innovations in the HSR industry. Does it require very broad general knowledge that requires a lot of complementary technologies to fully make use of the innovation, or does it require a niche and specified field of study where once a particular breakthrough is achieved, the industry innovation is done?

The four parameters of the technological regime highlight the pre-conditions that a country must work out in the development of a new, innovative industry. They represent issues that face the setting up of a new industry. Remiss to address any concerns in the four parameters will set back the innovation process at the meso-level.

Neo-Schumpeterian analysis focuses in technological foundation in the setting up of new industry. It puts the opportunity to acquire the necessary technology for that industry as the number one challenge. This is particularly relevant for fast changing industries that are capital and technology intensive. Any missteps in keeping up with evolving technologies easily eliminate the lagging player from the market. The appropriability parameter relates to the economic incentives to attract aspiring players to the industry and keep the existing players to continue their innovation and reinvestment endeavours. The cumulativeness parameter represents the extent of implicit knowledges that is required to succeed in the industry. The knowledge base is a measure of the complexity of the products and its linkage with other industries. Three of the four parameters relate to the nature of the industry and they are more technical in nature rather than economic in nature[131].

Findings: China's HSR industry and its market success

[131] Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological Regimes & Schumpeterian Patterns of Innovation. *The Economic Journal, 110*, 388-410.

The first modern Chinese HSR line (117 km connecting Beijing and Tianjin) commenced operation on August 1, 2008[132]. By the end of 2015, the total length of the HSR system is more than 19,000 km, providing 4,200 trips daily with a passenger capacity of 4 million per day. During that year, the HSR system carried 1.161 million passengers, accounted for 45.8% of all rail passengers. The on-time departure rate was 98.8%, and the on-time arrival rate, 95.4%.

During 2016's peak Spring festival travel season, the HSR hit a daily record of 6.28 passengers. Up to mid-2016, it has carried more than 5 billion passengers. This is 3.74 billion more passengers since the July 23, 2011 Wenzhou train accident[133]. The European Rail Authority (ERA) and International Train Union (UIC) classify the Chinese HSR system as one of the most reliable and safe railway system in the world[134,135].

In November 2015, China agreed to build the 150 km Jakarta-Bandung HSR system over 3 years using the Chinese standard, covering line design, line construction and rolling stock acquisition to daily operation. It was only in 2015

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132 The 405 km standard-gauge, dual track, electrified Qinhuangdao-Shenyang passenger rail was built between 1999 and 2003, it supports commercial train service at 200-250 km/h and it is the first truly high speed railway line in China. However, the train used then was the experimental Chinese designed model and different from the foreign train technology brought in under technological transfer agreement in 2004. Today's Chinese HSR industry was built under the technological foundation of the 2004 transfer. Hence most experts consider the August 1 2008 Beijing-Tianjin HSR operation should be considered the inaugural run.

133 A train hit by power outage in the thunder storm and stationary on the track was hit by a running train on its rear near Wenzhou on July 23, 2016. One car fell from the viaduct and cause 40 dead and 192 injuries.

134 Chinese high speed network to double in latest master plan. (2016, July 21). Retrieved July 22, 2016, from http://www.railwaygazette.com/news/infrastructure/single-view/view/chinese-high-speed-network-to-double-in-latest-master-plan.html

135 Chinese High Speed Rail carry more than five billion passengers since inception 中国动车组累计发送旅客破 50 亿人次. (2016, July 21). Retrieved July 22, 2016, from http://companies.caixin.com/2016-07-21/100968820.html?cxw=Android&Sfrom=Email

that the full set of indigenously-developed HSR system (380km/h top speed CRH 380) was successfully modified. The move to Chinese standard on all phases of the HSR means that China had almost completely localized the HSR industry. From 2004 to 2015, the country managed to progress from a technology importer to an exporter. This is a rare industrial development in this technologically intensive field. Currently, the local content of Chinese HSR rolling stock ratio is reportedly 90% upward, with all design and part parameters being Chinese in origin[136].

The HSR industrial development also carries significant social and economic implications for China. The HSR carried 1,161 million passengers in 2015, almost three times the volume of airline passenger throughput of 430 million. The significant passenger transportation capacity increase from the HSR facilitated the development of a single national market in labour and goods. The rail cargo capacity boost from the diversion of the rail passengers in conventional track to the dedicated passenger line also facilitated the lowering of national logistic cost. It was estimated that in 2015, the relatively energy-efficient rail system carried a combined 25% of national passenger and cargos, while its share of energy consumption in the transportation sector was only 6%[137]. Financially, in 2015, it was reported that at least 6 of the HSR lines generated net profit, and that the 1,318 km Beijing-Shanghai HSR was the most profitable HSR line in the world, carrying 130 million passengers and generating more than USD 1 billion in net profit. The exclusive HSR operator, China Railway Corporation (CRC), is meeting its financial

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[136] Shen, J. (n.d.). Local content of Chinese High Speed Rail Rolling Stock. Retrieved July 16, 2016, from http://www.zhihu.com/question/28006897

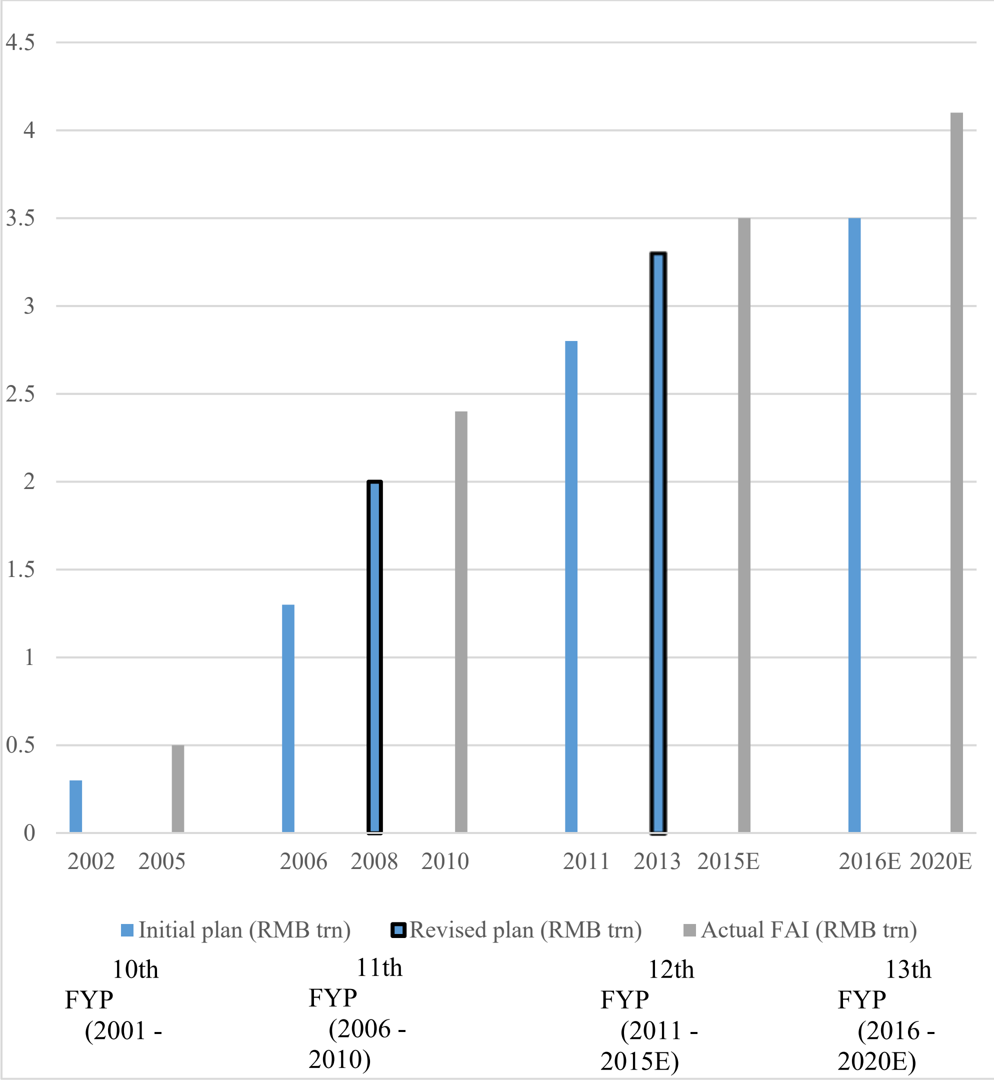
[137] Chinese High Speed Rail carry more than five billion passengers since inception 中国动车组累计发送旅客破 50 亿人次. (2016, July 21). Retrieved July 22, 2016, from http://companies.caixin.com/2016-07-21/100968820.html?cxw=Android&Sfrom=Email

target even it is running a HSR building blitz[138].China's HSR has been successful in both domestic and international markets. More importantly, it apparently meets both the government's social and transportation objectives of the HSR industry.

The Chinese economy is facing a structural headwind with growth slowing down to 6.7% in the first half of 2016. The government is using the HSR industry and its related urban railway transport industry to anchor the infrastructure spending to support economic growth. The Chinese government published a "Three-year (2016-2018) action plan for the construction of major transportation infrastructure facilities" in July 2016. This action plan provides a comprehensive list of 303 major projects with total investment of RMB 4.7 trillion, and involves railways, waterways, airports and urban railway transits. Over three quarter of the transportation plan is earmarked for rail related infrastructure. The plan includes 86 railway projects with total length of 20,000km, and 103 urban transit projects with total length of 2,000 km. The estimated costs are RMB 2 trillion and RMB 1.6 trillion respectively.

As shown in the table below, during the past 5-year plans, actual fixed asset investment on rail industry always exceeded the initial and the revised plan. This shows that the government has confidence on the development of the HSR industry.

[138] At least six High Speed Rail line makes money now. (2016, July 22). Retrieved July 22, 2016, from https://view.inews.qq.com/a/FIN2016072200580208



Source: UBS[139]

Fig 67. Actual versus planned Railway Fixed Asset Investment in Five-Year Plan

Chinese HSR before 2004

In the early 1990s, Chinese commercial train service ran at an average speed of only 48 km/h under a congested railway network, steadily losing its market share to air transportation and the expanding highway network. In 1992, the central

139 Xu, R. (2015). *China Railway Sector-Positive on rail FAI in 13th FYP* (pp. 1-60, Working paper). Hong Kong: UBS.

government adopted the Ministry of Railway (MOR)'s proposal to develop a high-speed railway system as the next backbone of rail system in China. *the Railway Development Plan in the next 10 years and under Eighth Five-Year Science Development Plan* marked the start of China's high speed rail development. However, raging debates ensued inside China on whether the country should adopt conventional high speed wheel technology or maglev technology, and whether it should develop the technology indigenously or adopt the then- overseas operating Shinkansen, TGV or ICE technologies. The arguments caused significant delay in the HSR project implementation and the inaugural 117 km Beijing -Tianjin HSR line's construction started only in 2005.

In 2004's *Mid-to-Long Term Railway Development Plan*, the State Council adopted conventional track technology as the backbone of China's HSR system. The plan decided to stop indigenous HSR train development program and bring in foreign technology, clearing the way for rapid construction of standard gauge (1,435mm) and passenger-dedicated HSR lines in China. It envisioned the total HSR network to be 12,000 long by 2020 with 4 major East-West Horizontal trunk line and 4 North-South Vertical trunk line, and the total national railway to be 100,000km[140].

[140]The four vertical dedicated passenger HSR lines include the following: 1. Beijing-Shanghai Passenger Line-1318 km. 2. Beijing-Wuhan- Guangzhou-Shenzhen Passenger Line-2229km. 3. Beijing-Shenyang-Harbin (Dalian) Passenger Line- 1700km. 4. Hangzhou-Ningbo-Fuzhou-Shenzhen Passenger Line-1495 km.

The four horizontal dedicated HSR lines include the following: 1. Xuzhou-Zhengzhou-Lanzhou Passenger Line-1363 km. 2. Shanghai-Kunming Passenger Line- 2066 km. 3. Qingdao-Shijiazhuang-Taiyuan Passenger Line-873 km. 4. Shanghai-Wuhan-Chongqing-Chengdu Passenger Line-2078km.

On hindsight, MOR's decision to stop the development of indigenous HSR train is a good decision. China avoided further delay on HSR development and the failure taught its technical staff valuable lessons. MOR was able to make correct technological choice when it set up the HSR standard in 2004, particularly in the case of selecting distributed traction over the popular concentrated traction[141]. The R&D personnel involved in the failed domestic high speed train project were re-assigned to the various units working on the imported technologies and they absorbed the imported technology quickly[142].

[141] China bought foreign technology for 200 km/h train in 2004 and the decision to use distributed traction system facilitates the transition to subsequent higher speed train to 350 km/h. Experts suspect that the decision is based on the result of the Japanese HSR system as well as their own experience of difficulties in the R&D of China Star with concentrated traction, as against Changbaishan with distributed traction.

[142] In the case of the failed China Star, the team leader became the team leader of CRH2A, and 90% of the core development team of CRH2A came from the former China Star R&D team as well.

EMU model	Year of production	Research manufacturer	Train set configuration	Designed maximum/ operating speed (km/h)	Passenger capacity (persons)	No. of production units
KDZ1	1988	Changchun Zhuzhou RI	2M2T	140/141	191	1
X2000 (new speed per hour)	1998	ADTranz	M + 6T	210/200	415	1
DDJ1(Shark)	1999	Zhuzhou E, Changchun Sifang, Tangshan, Nanjing	1M6T	220/200	438	1
KDZIA (Spring City)	1999	Changchun, Zhuzhou RI	3M3T	140/132	180	1
DJJ1 (Blue Arrow)	2000	Zhuzhou E, Changchun	1M6T,2M10T	235/200	423/752	8
DJFI1(Star of Central China)	2001	Zhuzhou M, Sifang, Zhuzhou RI, Zhengzhou	8M6T,4M2T	178/160	548/1398	1
DJF2(Pioneer)	2001	Nanjing	4M2T	200/160	424	1
DJF3(Changbei Shan)	2003	Changchun	6M3T	210/160	650	2
DJJ2 (Star of China	2002	Zhuzhou, Datong, Changchun, Sifang	2M9T	270/160	673	1

Fig 68. Chinese indigenous high speed train model developed before 2004. Source: Author's collection

While the HSR discussion was ongoing, MOR embarked on a series of nationwide "Speed Up" campaigns to increase the service speed and capacity on existing lines between April 1994 and April 2007. The focus of the “Speed Up” exercise was to gradually increase train speeds on existing routes while also developing Chinese know-how in all aspects of rail infrastructure and train operation. Between 1997 and 2001, the maximum speed of conventional trains operated with locomotives increased from 100 km/h to 160km/h on around 13,000 km of passenger routes.

Measures employed in the "Speed Up" campaign included double-tracking, electrification, improvements in grade (through tunnels and bridges), improvements in turn curvature, installation of continuous welded rail, development of new locomotives and modernizing of signaling systems. The new technologies employed in these projects were almost all developed indigenously. This experience not only helped China to become the world technology leader in the upgrading of conventional track to either sub-high speed passenger lines (top speed below 200 km/h in the route) or combo cargo-passenger line. It also laid the foundation for the subsequent setting up of unique Chinese specifications in track construction and speedy absorption of HSR technologies from foreign joint venture partners[143]. Upgrading existing tracks to run sub-high speed train is a technological area often neglected by major developed countries' rolling stock companies, but this know-how offers significant economic benefits to developing countries where old rail network can be rehabilitated to provide cheaper alternatives. The Chinese HSR track specification is the most significant differentiation factor between Chinese HSR and that of Shinkansen, TGV and ICE.

The failed attempt to build an indigenous HSR train before 2004 still helped China to build up a local technology base on HSR rolling stock development. In contrary to common perception that the success of the Chinese HSR industry relied on economics of scale, the successful localization of the industry also contributed

[143] The Qinhuangdao-Shenyang line shown the greater compatibility of HSR on conventional track with the rest of China's standard gauge rail network.

to the Chinese government's subsequent decision to support the expansion of the HSR program.

The acquisition and assimilation of foreign rolling stock technology (2004-2007)

Compared to Japan's Shinkansen, Frances' TGV and Germany's ICE which first ran in 1964, 1981 and 1991 respectively, China is a late comer to the HSR industry. The construction of the Beijing-Tianjin HSR only started in 2005. In 2004, China suspended its indigenous high speed train development and opted to import HSR rolling technology under technology transfer agreements with foreign train-makers, including Bombadier, Kawasaki, Alstom and Siemens. Under the agreements, MOR also tasked its two rolling stock manufacturing arms, China South Rail (CSR) & China North Rail (CNR), to work with foreign technical partners to produce rolling stock for the HSR project[144]. The electric multiple unit (train sets) produced were given the titles CRH-1 to CRH-5 (CRH stand for China Rail High Speed):

(1) The CRH-1 series is produced by Bombardier's joint venture CSR Sifang (Qingdao) Transportation (BST)[145];

- CRH-1A: an 8-car version train; maximum operating speed of 250 km/h, derived from Bombadier Regina design.
- CRH-1B: a modified 16-car version; maximum operating speed of 250 km/h, derived from Bombadier Regina design.

[144] CSR & CNR were merged at mid-2015 to form China Railway Rolling Corporation (CRRC)
[145] Bombardier rail division is based in Germany and the technology is considered of German origin.

- CRH-1E: a 16-car high-speed sleeper version; maximum operating speed of 250 km/h, derived from design of Bombadier Zefiro 250.

(2) The CRH-2 series is produced by CSR Sifang under license from Kawasaki. The design is derived from the Shinkansen E2-1000 series.

- CRH-2A: 8-car version; maximum operating speed 250 km/h.
- CRH-2B: modified 16-car version of CRH-2; maximum operating speed of 250 km/h.
- CRH-2C (Stage one): 8-car version; maximum operating speed of 300 km/h.
- CRH-2C (Stage two): 8-car model; maximum operating speed of 350 km/h.
- CRH-2E: 16-car version of CRH2 with sleeping cars, maximum speed of 250km/h.

(3) The CRH-3 is produced by CNR, under license from Siemens ICE-3 (class 403)

- CRH-3: 8-car model, maximum operating speed of 350 km/h.

(4) The CRH-5A is produced by CNR, under license from Alstom. It is derived from the Alstom Pendolino ETR 600.

- CRH-5A: 8-car model, maximum operating speed of 250 km/h.

In the 2004 HSR development strategy, the Chinese government set several important rules which contributed a lot to the speedy absorption and progress of the technology over other global peers. The success of the technology would not be possible without these rules:

First, HSR track construction was based on Chinese specifications. The new specifications allowed China to adopt both the best practices available as well as incorporate its local indigenous innovation. In other words, China exploited the late comer advantage and designed a HSR system better than existing networks[146]. The decision to set up an entirely new specification in track infrastructure was in sharp contrast with that of the three technology leaders of HSR at that time: Japan's track infrastructure remained essentially the same since its inception in 1964, and the TGV and ICE ran on mixed HSR and conventional train track basis. China's unique track feature accords optimum compatibility between the train and its dynamic environments[147], allowing the HSR to operate at the highest average speed today with upmost comfort.

Second, all the 4 builders of the HSR train must be domestic corporations, and they must commit to integrate all domestic innovations in the communication,

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[146] The country use ballastless slab rail bed design, long-span bridge, elevated viaduct and many latest construction methods in the HSR rail line construction. China innovated on the imported slab technology and the country is the only one in the world now that can build HSR under all soil condition, weather condition.

[147] China pioneer many important innovations in track construction: extensive use of no ballast slab track construction, high turning ratio of 7km at 350km/h, 5.5 km at 200 km/h, maximum tunnel diameter of 10 meter, maximum line spacing of 4.8 meter between two tracks, extensive use of bridge/viaduct in passenger dedicated lines. These innovations allow Chinese HSR to run at much higher average speed than Japanese and European HSR lines. The highest average speed of Chinese line runs at 299 km/h for the 1433 km Beijing -Shanghai line. The highest European line runs at 250 km/h for Paris-Lyon and Japanese Tokyo-Osaka average speed is 230 km/h.

scheduling, and operation of the passenger service and power traction systems. These ensure the continuing development of indigenous technology[148].

Third, China insisted most of the train sets ordered to be produced in China with technology transfer fee paid and made as part of the purchase[149]. This policy facilitated the development of the Chinese indigenous HSR rolling stock industry. Today, there are two HSR manufacturing clusters around the former CSR production base at Zhuzhou and Hunan, and another two clusters around former CNR production base at Changchun, Jilin[150].

Fourth, China chose distributed traction over conventional traction, a decision that was lauded as a smart technological choice. It excluded many popular choices such as the French TGV and German ICE-1, and all of the introduced CRH1, CRH2, CRH 3 and CRH5 used distributed traction[151].

The indigenous technological breakthrough and building of the local HSR industry (2009-present)

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[148] The HSR industry foreign technology importation is not a case of market for technology. The transaction is an outright technology purchase. China use its market size as a carrot in price negotiation but there is no assurance on subsequent purchase. Out of four foreign technology supplier, only Bombadier formed a joint venture to manufacture the trains. The trains were imported or built under technology transfer agreements with foreign technology provider. Chinese engineers then redesign and improve internal parts and come out a better product.

[149]Alstom order of 60 units 200 km/h train set at euro 620m include transfer of 7 core technologies. 3 set were imported, 6 were CKD assembled in China, rest produced in China. Kawasaki order of 60 units 200km/h at RMB 9300m also include technology transfer, set number under importation, CKD and local produce the same as Alstom. Bombardier order of 40 units 200 km/h and 40 units 300 km/h train sets from the only Sino-Canadian joint venture are locally source. Siemens order of 60 units 300 km/h train set at euro 669m also include technology transfer and 3 imported set, 57 locally produced set.

[150] CSR and CNR were merged in 2015 to form CRRC.

[151] Sone, S. (2015, October). Comparison of the technologies of the Japanese Shinkansen and Chinese High-speed Railways. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering), 2015*(10), 760-780.

MOR had set assimilating imported HSR technology at the top of priority when they licensed the imported technology in the mid-2000s.[152] Chinese train-makers, after receiving transferred foreign technology, assimilated the imported technology and developed a considerable degree of self-sufficiency in making the next generation of high-speed trains by 2008.

By 2008, China was confident on the progress of its HSR industry and revised the *2004 Mid-to-Long Term Railway Development Plan*, raising the National HSR total length target from 12,000 km to 16,000 km in 2020. Likewise, the total railway length was revised from 100,000 km to 120,000 km. In 2008, the Chinese government issued *Action Plan for the Independent Innovation of Chinese High-Speed Trains* which aims at building an HSR technology innovation system based on technology import. MOR, together with the Ministry of Science and Technology (MOST), took the lead in the implementation of the plan.

From 2008 to 2010, the National Natural Science Foundation of China sponsored 55 HSR-related R&D projects. Out of this 55 projects, 33 were dedicated to localize and improve the imported technologies and the rest were dedicated to develop local indigenous technologies. MOR and MOST consolidated 11 research institutes, 25 universities, 51 national laboratories, 2 manufacturing State Owned Enterprises (SOE), CSR and SNR to participate in the R&D projects. 63 fellows from the Chinese Academy of Science and Chinese Academy of Engineering, over

[152] China had identified nine key subsystems in HSR rolling stock – aerodynamics of the Electric Multiple Unit(EMU) train body, bogies, traction control systems, traction transformers, converters, traction motors, braking systems, network control systems, EMU system integration technology.

500 university professors, 200 research fellows and 10,000 technical staff participated in the R&D projects.

From basic research, applied research and laboratory prototype testing all the way to manufacturing, China developed a complete HSR technology industry ecosystem by the turn of the first decade of 21st century. From 2008 to 2010, Chinese companies applied for 1,284 patents and accounted for 72% of total HSR-related patent applications from 1985 to 2011. China holds many new patents related to the internal components of the new train sets indigenously developed. These indigenously design new train set were based on original foreign design with re-designed major components to allow the trains to run at a much higher speed than the original foreign train design. China has developed indigenous technology in the 380 km/h category and the models CRH 380-A, CRH 380-AL, CRH 380-B, CRH 380-BL, CRH 380-CL were all locally designed and built[153]. The only foreign participation in China's rolling stock industry is the Bombadier Sifang Transportation (BST)'s production of CRH 380-D (known as Zefiro 380 internationally) and CRH 380-DL. The most popular model today in the Chinese 380 km/h market is CRH 380-A. Unveiled in 2010, the CRH380A possessed world class technologies in traction converter, network control, aerodynamic body design and high speed bogie.

China also used foreign merger & acquisition (M&A) to access critical missing technology. Notable cases are the 2008 acquisition of UK's Dynex Power by CSR for RMB 93 million (75%), as well as the 2015 acquisition of BOGE by

[153] The first CRH 380A indigenously designed train was built on the original foreign standard. The first Chinese CRH380A was built in 2015 only in 2015.

CRRC for RMB 2.4 billion (full ownership). The first acquisition was to obtain access to IGBT power module technology, while the latter was to obtain shock absorbing rubber technology[154].

CRRC had set up 9 overseas R&D centers to work on leading foreign rail technology. It runs a corporate central research station, 8 national key engineering laboratories, 4 professional research institutes, 4 national engineering technology research centers, and 20 national level corporate technology centers. The research budget in 2015 was RMB 9.95 billion or 4.2% of sales, and almost 10% of its 190,000 staff worked in R&D[155].

China is not in the cutting edge of rolling stock manufacturing space and *Made in China 2025* is going to address the problem. The size of CRRC and the R&D resources committed will facilitate the catch-up.

The state of the Chinese railway industry

Since the introduction of HSR service in 2007, China has built the world's most extensive HSR network with operating length more than half of the world's total[156]. China’s HSR can be broken down into 4 sub-groups: the newly built passenger designated lines (PDLs) that only provide passenger service; the newly built conventional rail lines mostly in western China which can carry high-speed passenger and freight trains; certain regional "intercity" HSR lines that are also dedicated to passenger service alone; the conventional track railways that were

[154]In 2015, Chinese government merged CSR and CNR to form CRRC, the company become the sole manufacturer of HSR rolling stock in China.
[155]CRRC Annual Report 2015. (2016, April 27). Retrieved July 22, 2016, from http://www.hkexnews.hk/listedco/listconews/SEHK/2016/0427/LTN20160427686.pdf
[156] The definition of HSR is based on top speed and many lines are operating at top speed only in a short section of its track. In this regard, China’s share of world HSR is often put at more than 60%.

upgraded to run mixed passenger and freight lines. Most of the rail lines currently under construction belong to one of the first three categories. Nearly all HSR lines and rolling stock in China are owned and operated by the CRC[157].

The development of the Chinese HSR took place on a scale beyond anything the world has ever seen. In June 2016, the Chinese government again revised the 2008 railway development plan, envisioning the HSR line to reach 30,000 km and national railway length to hit 150,000 km by 2020[158].

Country	In operation (km)	Under construction(km)	Total country (km)
China	19,000	18,155.5	37,155.5
Spain	3,100	1,800	4,900
Japan	2,664	782	3,446
France	2,036	757	2,793
Sweden	1,706	0	1,706
Turkey	1,420	1,506	2,926
United Kingdom	1,377	0	1,377
Germany	1,334	428	1,762
Italy	923	125	1,048
South Korea	819	613	1,432
Rest of the world	**2821**	**1482**	**4303**
Total	**37200**	**25648.5**	**62848.5**

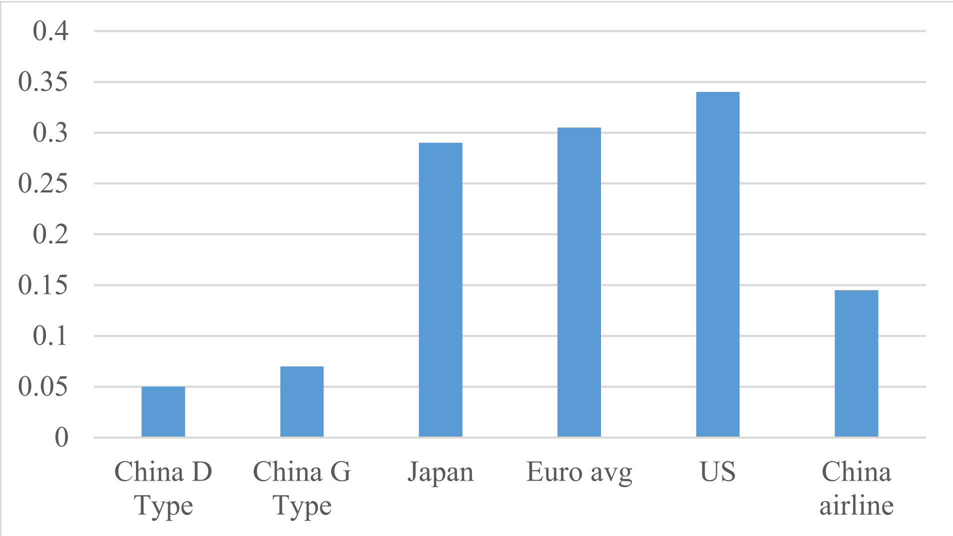
Source: author tabulation

Fig 69. High Speed Rail in the world as of Dec 2015

[157] MOR was dissolved in March 2013 and its railway operating asset was taken over by China Railway Corporation (CRC). The policy formulation function was assumed by Ministry of Transportation and the government oversight function was taken over by a rail transport board.
[158] Xu, R. (2016). *China Construction-RMB 4.7 train transportation infrastructure construction plan for 2016-2018*. Manuscript, UBS, Hong Kong.

Benefits of the Chinese HSR to the economy:

Aside from the convenience of shorter travel times, the key to the successful migration of ordinary train passenger to HSR lies in its affordability[159]. From the perspective of absolute fare to relative fare, the Chinese HSR is below. From perspective of both relative fare to income and absolute fare level, figure 71 and figure 72 indicated that HSR is affordable to the Chinese commuters.



Source: UBS[160]

Fig 70. China HSR train passenger ticket price compared global and China airline (US$/km)

[159] During 2008-2013, total rail passenger volume continued to grow at 7.6% annually, but with a change in traffic composition. While conventional rail traffic grew 1.5% annually, HSR traffic has increased 39% per annum since 2008. The introduction of CRH services has not caused a reduction in ridership on the conventional network, but has instead fuelled accelerated growth, which the previous network, close to its full capacity, was unable to serve.

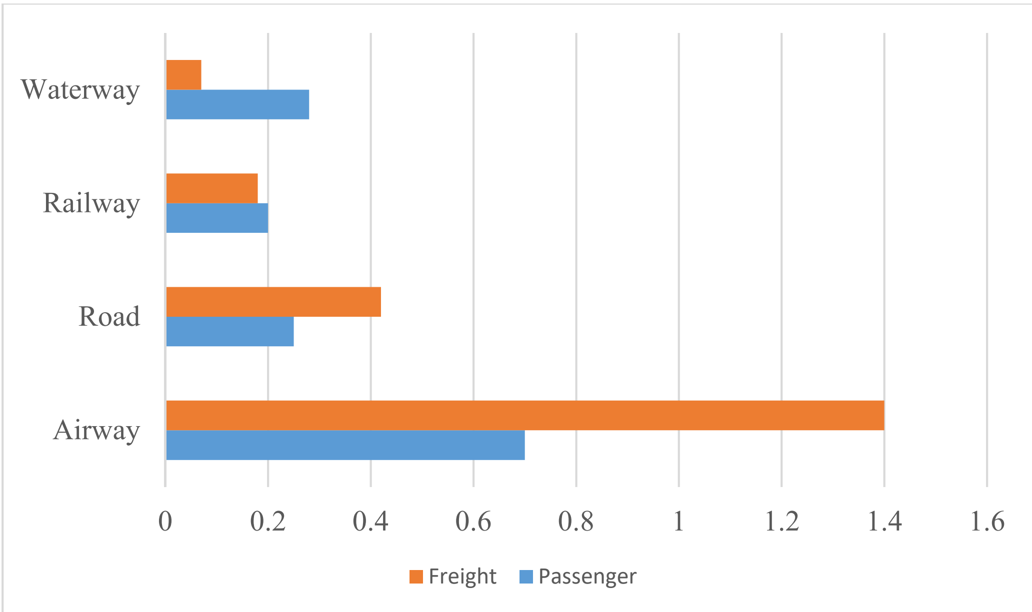
[160] Chan, H. (2016). Prospect of Chinese Rail Export Under "One Belt, One Road" In *China's One Belt One Road Initiative* (pp. 197-236). London, UK: Imperial College Press.

	Nominal HSR fare-euro/km	Average Monthly salary(euro/month)	percentage of monthly income per 100km HSR
China	0.04	500	0.80%
Spain	0.19	1800	1.05%
France	0.22	2210	0.81%
Germany	0.27	2080	1.29%
Italy	0.25	1870	1.33%
Japan	0.22	1930	1.14%

author's calculation based on 2013/1/15 Takungpao

Fig 71. HSR fare as percentage of monthly income per 100km

The spillover effects of HSR to the efficiency of the economy are very positive. Compared to other means of transportation, railway has overall cost advantages.



Source: author calculation based on MOR, MOC data as of Jan 2013. All fare in RMB/km

Fig 72. Railway has cost advantage vs. other transportation means

In terms of energy efficiency, it also compares well with other modes of transportation[161].

[161] Table on energy consumption use SCE (Standard Coal Equivalent) as energy measurement unit, 1 SCE=8.14 kwh

	Cargo kg SCE/kt.km	Passenger kg SCE/person.km
Ordinary Railway (diesel)	3.6	0.018
Ordinary Railway (electrified)	1.4	0.007
High-speed Railway (electrified)	Na	0.01
Land vehicle	18.2	0.015
Cars	Na	0.043
Shipping	3.1	na
Civil Aviation	91	0.068

Source: logistic Companies, Shipping companies, airline companies, Both Merrill Lynch Global Research estimates.

Fig 73. Energy consumption comparison of the different modes of transportation

1 standard coal unit = 8.141 kwh

Traditional economic evaluations of major transport infrastructure focus on the direct costs and benefits arising from travel, including user time savings, operator cost savings, and reduction of externalities like air pollution, noise, and accidents. Wider economic impacts are too tenuous to be reliably quantified and therefore often neglected. However, in the years following the adoption of HSR, China has surprisingly shown strong economic agglomeration benefits[162]. This significant economic growth effect from agglomeration in favour of city cluster encourages the formation of 3 mega growth areas in China: Beijing-Tianjin-Hebei; Yangtze River Delta; and Pearl River Delta. China's drive to build intercity HSR in recent years is quite unique in the world HSR construction history. This reflects that economic agglomeration effects in China is becoming more and more apparent.

[162] In economies, agglomeration are the benefits that firms obtain by locating near each other. This concept relates to the idea of economies of scale and network effects. As more firms in related fields of business cluster together, their costs of production may decline significantly (firms have competing multiple suppliers; greater specialization and division of labor result). Even when competing firms in the same sector cluster, there may be advantages because the cluster attracts more suppliers and customers than a single firm could achieve alone.

A World Bank study noted the unusually strong contribution of HSR to China's regional economic development, urbanization and industrial upgrading[163]. Although benefits from these three areas are too early to be quantifiable, Chinese experience does show a dynamic interaction of properly executed transportation infrastructure and economic growth in both short to long term. Chinese successes in HSR have drawn the attention of many developing countries.

An interesting technology spillover area from China's development in HSR is in the area of urban rail transport. Urban rail transport includes subway and light rail, with tram and maglev being an insignificant player. China has intensified urban rail transport infrastructure investments to improve the city traffic conditions. Cost estimates based on approved lines show that China in general spent around RMB 500-700 million/km (USD 80-110 million/km) on city subway construction. This figure is very low by international standards and most observers believe that the Chinese civil work and rolling stock contractors achieved such efficiency through the learning curve from the HSR construction. By the end of 2015, 23 Chinese cities are running their urban subway rail networks and China will expand its urban rail network significantly in the next few years[164]. Figures below shows the Unit investment of urban rail transit and operating length of urban rail transit system in China. Recently announced Chinese plan confirmed the expansion of urban rail system to at least 8000 km by 2020.

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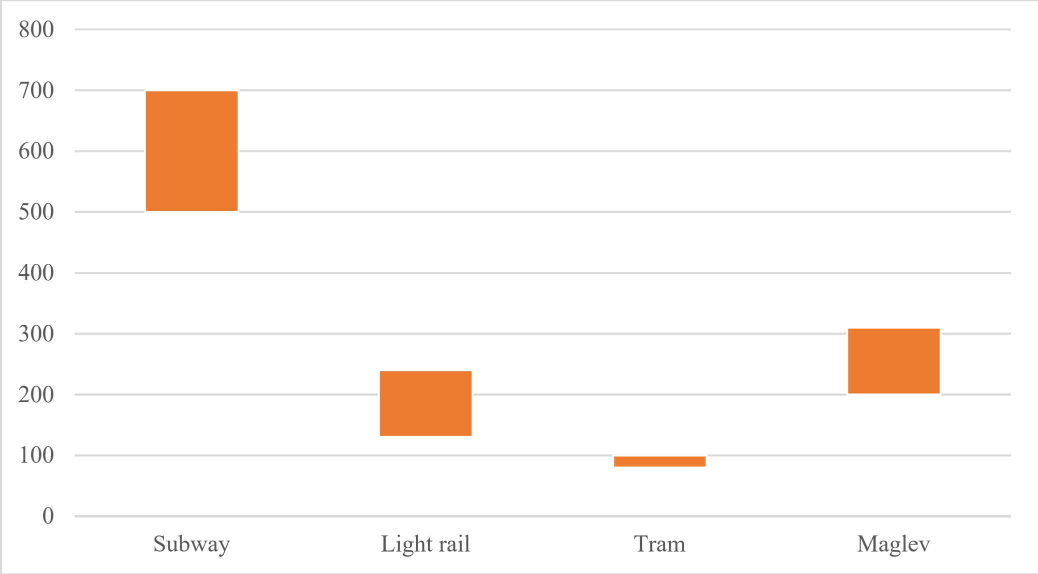
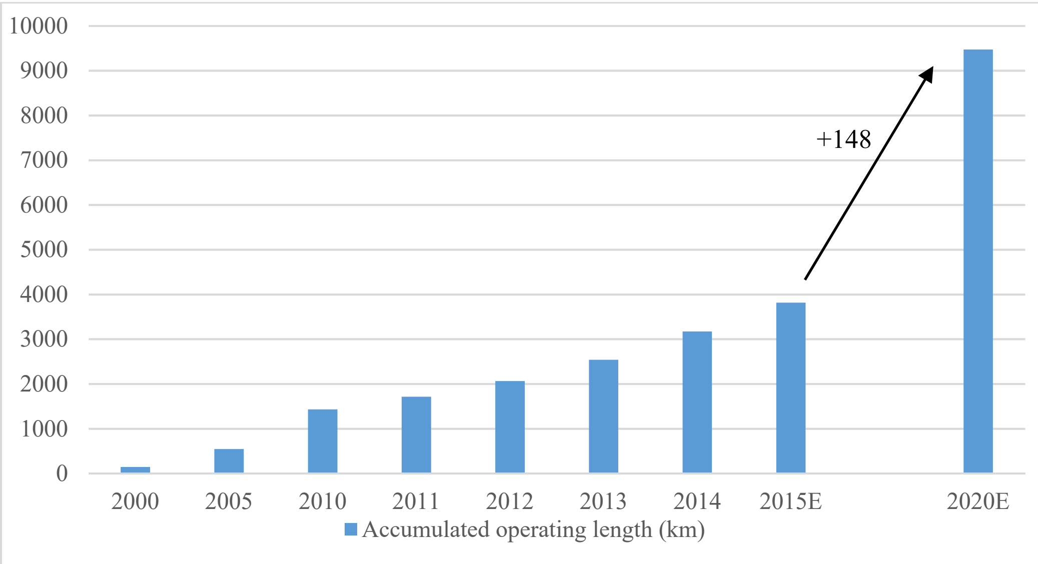
[163] Andrew Salzberg, Richard Bullock, Ying Jin and Wanli Fang, "High-speed rail, regional economics and urban development in China", World Bank Office (Beijing), *China transport topics*, No. 08, January 2013

[164] 23 cities running subway are Beijing, Changsha, Chongqing, Chengdu, Dalian, Guangzhou/Foshan, Hangzhou, Harbin, Hong Kong, Kunming, Nanjing, Nanchang, Ningbo, Qingdao, Shanghai, Shenyang, Shenzhen, Suzhou, Tianjin, Wuhan, Wuxi, Xian, Zhengzhou.



Source: UBS estimate.[165] All price in RMB/km

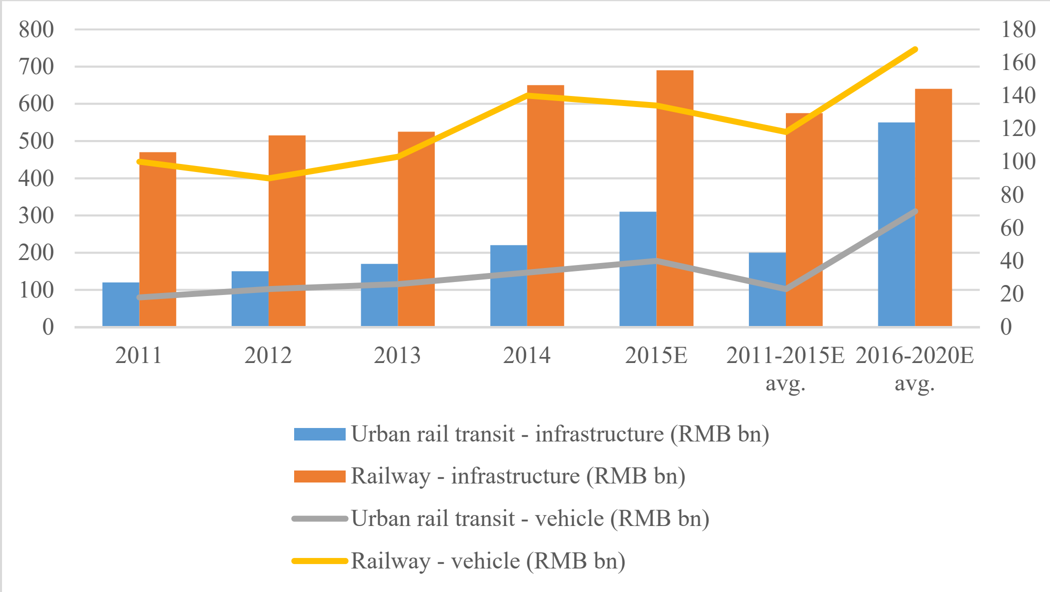
Fig 74. Unit investment in RMB/km for Urban Rail Transit



Source: UBS estimate. [166]

Fig 75. Operating Length of the Urban Rail Transit System in China

[165] Chan, H. (2016). Prospect of Chinese Rail Export Under "One Belt, One Road" In *China's One Belt One Road Initiative* (pp. 197-236). London, UK: Imperial College Press.
[166] Xu, R. (2016). *China Construction-RMB 4.7 train transportation infrastructure construction plan for 2016-2018*. Manuscript, UBS, Hong Kong



Source: UBS estimate[167]

Fig 76. Past and planned Fixed Asset Investment on urban and railway in China

Innovations in the Chinese HSR industry

There are four major players in the global HSR industry: Japan (1964), France (1981), Germany (1991) and China (2007)[168]. In contrast to the first three countries that develop the HSR technology through independent research and development, the Chinese used a different strategy to develop HSR technology. It first built a local technological base, then skillfully introduced foreign technology to fill the knowledge gap, absorbed and improved the foreign technology, and then combined with indigenous improvement to build a more efficient industry.

Industry experts often use the maximum train speed as a generation definition for HSR. The first generation 1G train runs between 200-300 km/h, 2G train runs around 300 km/h and 3G train runs around 350 km/h. Following this definition, we noted that China had compressed its transition from 1G to 3G in three

[167] Ibid.

[168] Parenthesis indicate the year in which the first HSR line operates in that country.

years using initially CRH1, CRH2, CRH5 in 1G and CRH 380A, CRH 380B in 3G (2007-2010) as against Japan's transition of 47 years (1964-2011), France's transition of 27 years (1981-2008) and Germany's transition of 15 years (1991-2006).

Generation	Japan	France	Germany	China
	Model Max. Speed (year introduced)	Model Max. Speed (year introduced)	Model Max. Speed (year introduced)	Model Max. Speed (year introduced)
1G	**S-0** 210km/h (1964) **S-100** 210km/h (1975) **E-2** 275km/h (1997)	**TGV-PSE** 280km/h (1981) **TGV-A** 300km/h (1989)	**ICE-1** 250km/h (1991) **ICE-2** 280km/h (1996)	**CRH1** 200km/h **CRH2** 200km/h **CRH5** 200km/h **Imported 1G**
2G	**S-500** 300km/h (1998)	**TGV-Mediterranee** 320km/h **TGV-EST** (2001) 320km/h (2007)	**ICE-3** 300km/h (2002) (Valaro)	**CRH2** 300km/h **CRH3** 300km/h 350km/h EST (2008) **Developed** 2G
3G	**Fastech 360** (2011) Reduced to 320km/h, as E5 was put in service	**AGV360** (2008) Tested 360km/h EST in Italy, by 2013 (not over) 300km/h EST	**ICE350E** (2006) Tested 350km/h EST in Spanish (not in service)	**CRH380-A** **CRH380-B** (2010) 350-380km/h In service **Created 3G**

Source: author tabulation

Figure 77-Timeline of technology development for HSR train around the world

China exploits both the inefficiency of its global peers and its natural economics of scale and late comer advantages to overcome the disadvantage of insufficient technical experience in one of the most technically intensive and safety centric industry[169].

[169] There are more than 12000 mechanical parts in a high speed running train and the Chinese name of CRH (hexie-和谐) means that the train parts should work in harmony. Also the consequence of a running high speed train accident is fatal.

While the attention on HSR system often falls on the train speed, China's global peers all failed to take action on their country's track design in complementing the dynamic running condition of a high-speed train. In the case of Japan, its maximum line spacing between parallel track is set at 4.3 meter-4.5 meter, turning ratio is set at 4-5 km, and tunnel diameter at 8 meter. This restricts the maximum speed that train can run in many aerodynamic sensitive areas. In the case of France, it did not use elevated viaduct extensively in its line and the roadbed system restricted the turning ratio. Hence this restricts the maximum speed where trains can also run in many areas. In the case of Germany, though it pioneered many infrastructure parameters to improve train-track coordination, it often failed to provide for dedicated high speed passenger track lines for the whole route. Passenger dedicated high speed train run at high speed track in some parts of the route and then slowdown at the upgraded conventional track when it reaches that section. The incoordination of track and train hamper the speed transition of Japan, France and German trains from 1G to 2G to 3G[170,171].

The absence of a good track infrastructure placed all the system adjustments on the running trainset system. This incoordination reflects the absence of a centrally organized system setup at the beginning. While China is a late comer, it had noted all the earlier problems of its peer. Its track parameters reflect the optimum compatibility of train and track[172].

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170 Liu, X., Zhao, P., & Dai, F. (2011, September). Advances in design theories of high-speed railway ballastless tracks. *Journal of Modern Transportation, 19*(3), 154-162.

171 Minimum Railway Curve Radius. (n.d.). Retrieved July 21, 2016, from https://en.wikipedia.org/wiki/Minimum_railway_curve_radius

172 Wang, J. (2011, May 4). *The Ballastless Track Technology For China High-Speed Line*. Lecture presented at High Speed Rail Technology.

The unique Chinese track parameter and design criteria place a serious challenge on implementation and credit should be given to the Chinese for overcoming them. China had successfully localized the slab rail bed system and develop cost efficient viaduct/tunnel construction method[173]. Hence the Chinese HSR system run at higher average speed than its global peers. Better track-train compatibility also improves the riding comfort and safety of the train[174,175].

The successful adoption and improvement of imported technology plus the development of complementary construction techniques put the Chinese HSR industry in a strong comparative cost position. World Bank (WB) provided the earlier financing to some of the HSR projects and it probably has the best cost factor data aside from Chinese government. WB pointed out that China has a commanding cost advantage in turnkey HSR system, unit cost of PDL (passenger dedicated line) in Chinese HSR is about 1/3 to 2/3 to those of other countries[176].

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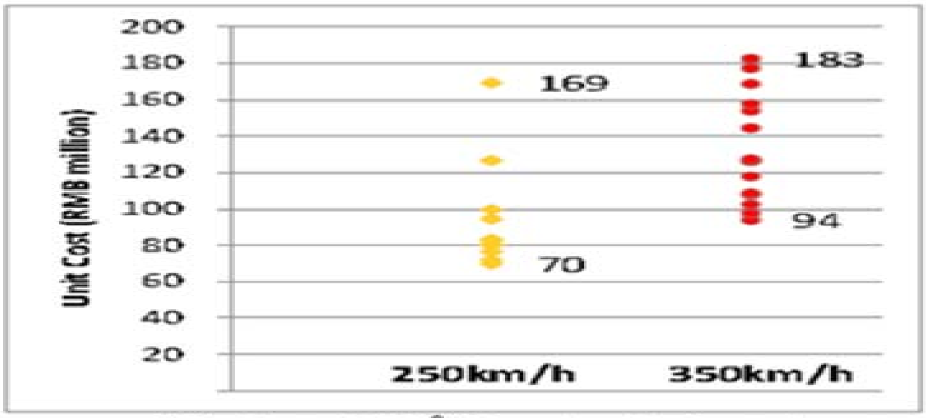
[173] It is estimated that the average viaduct length of a typical Chinese HSR line is around 55%, the use of viaduct and no ballast slab rail bed system solve many speed restricting design problems.

[174] A recent field test for CRH380A reveals at 486.1 km/h, the derailment coefficient is only 02 as against the security norm of 0.8, the ride quality indexes are 1.8 and 2.0 against the standards of 2.0 and 2.5 in lateral and vertical directions. The emergency brake distance at 380 km/h is 5908 m against the required 6500 meter.

[175] China use ballastless tracks that do not use rock material to stabilize them and also the entire line is seamless. The track construction required a lot of research work due to varying temperature across the rail line. The Chinese HSR are nearly all set in concrete slab which reduce wear and tear on the wheels and tracks.

[176] Gerald Olivier, Jitendra Sondhi and Nanyan Zhou, "High-speed railways in China: A look at construction costs", World Bank office (Beijing), *China Transport Topics*, No. 09, July 2014



Unit Cost of PDL[9] (Based on Estimated cost at the time of Project Approval) Source: Year books of China Transportation & Communications 2007-2013/China Railway Yearbooks

Source-World Bank data[177]

Fig 78. Unit cost of HSR (RMB/km) based on estimated cost at the time of project approval

WB identified two main reasons behind the Chinese cost advantage[178]. The first is the standardization of design of various construction elements which significantly enhances construction efficiency, and the second is the development of innovative & competitive capacity for manufacture of equipment.

World Bank cost analysis shows that construction cost is the most significant cost component in HSR project as shown in fig 80. China has used its scale advantage and developed a standardized design for various construction elements that significantly lowers costs. Figure 80 below is an example of such standardization of two specialized equipment developed on viaduct construction.

177 Chan, H. (2016). Prospect of Chinese Rail Export Under "One Belt, One Road" In *China's One Belt One Road Initiative* (pp. 197-236). London, UK: Imperial College Press.

178 Gerald Olivier, Jitendra Sondhi and Nanyan Zhou, "High-speed railways in China: A look at construction costs", World Bank office (Beijing), *China Transport Topics*, No. 09, July 2014

Figure 79 below shows the typical track civil work cost and the relatively small premium of viaduct over embankment cost as well as the low price of track.

Element	350km/h	250km/h	200km/h
Land acquisition and resettlement	4	4-8	6-9
Civil works	48	50-54	44-51
Embankment	6	7-12	13-15
Bridges/Viaducts	41*	13-25	25-27
Tunnels	0*	16-29	2-13
Track	9	9-11	6-7
Signal and communications	4	3	4
Electrification	5	4-5	4-5
Rolling stock	15	3-4	5-7
Buildings including stations	2	2-4	3-5
Other costs	Balance	Balance	Balance

**An exception is Shizheng Railway that has 69 percent of viaduct accounting for 41 percent of cost and no tunnels.*

Source- World Bank data[179]

Fig 79. Percentage of total project cost based on World Bank financed HSR lines

Beam Carrier

Beam Launching Equipment

Fig 80. Specialized beam carrier & launching equipment used in high speed rail viaduct construction

179 Ibid.

Element	350km/h	250km/h	200km/h
Land acquisition and resettlement	4	5-9	5-8
Civil works	57	56-62	42-43
Embankment	24	31-42	42-43
Bridges/Viaducts	71	57-73	59-62
Tunnels	--	60-95	51-68
Track			
Track(ballast-less)*	10	10-13	--
Track(ballasted)*	--	--	5-7
Signal and communications	5	3	3-4
Electrification	6	4-5	4

**Ballast-less slab track is under for 360 and 250km/h PDLs while ballasted track is employed for 200km/h railways.*

Source: PSR /PAD for projects. World Bank data[180]

Fig 81. Range of average unit construction costs of HSR lines financed by World Bank

(RMB in million per km of double track)

China HSR with a maximum speed of 350 km/h has a typical infrastructure cost of about USD 17-21million/km, with a high ratio of viaducts and tunnels. Similar construction in Europe, having design speed of 300 km/h, is in the order of USD 25-39 million/km. The figure is estimated to be as high as USD 52million/km for California. Chinese contractors have delivered projects within budget & construction time frames under the most difficult terrain conditions as shown in Table 5[181]. Budget overruns and delays are extremely rare[182]. For instance, World bank financed 857 km Guiyang-Guangzhou line traverses 270 tunnels and 510 valleys across the geographically difficult landscapes in Guizhou took only 6 years

[180] Ibid.

[181] The Guiyang - Guangzhou line is 1856km long with 83% of the tracks in tunnels & bridges, its maximum design speed of 250km/h. The project is completed in 5 years with the cost capped at RMB147m/km

[182] There is a delay of several months on project completion post July 2011 Wenzhou train accident, the government ordered a review of all projects under construction. However, all lines are finished on budget.

to complete with the final budget amended to RMB 94.6 billion on completion from initial budget of RMB 85.8billion estimated seven years earlier.

	Max. Speed Km/h/type	**Length Km**	**Total estimated cost RMB b**	**Unit cost RMB m/km**	**Bridges + Viaduct + Tunnels (% of route km)**	**Period of construction**
Shijiazhuang-Zhengzhou	360 PDL	366	43.9	123	69	2008-2012
Guiyang-Guangzhou	250 PDL	857	94.6	110	80	2008-2014
Jilin-Hunchun	250 PDL	360	39.6	110	66	2010-2014
Zhangjiakou-Hohhot	250 PDL	286	34.6	121	67	2013-2017
Nanning-Guangzhou	200 Mixed	463	41.0	89	53	2008-2014
Harbin-Jiamusi	200 Mixed	343	33.9	99	48	2014-2017

PDL-passenger dedicated line; Mixed- passenger/cargo combo line

Notes: 1. Total project cost includes the cost of project preparation, and acquisition of the railway and regular stations, con…., rolling stock and interest during construction. The cost of railway excluding cost of project preparation, rolling stock and interest during construction is estimated at about 82 percent of the total cost.

2. Cost Reference: GG-Revised FSR Dec. 2010, MG-PAD May 2009, Shi-Zheng PAD May 2008, Jitchun-PAD 2011, Zhang-Hu-FSR, Halia-Revised Feasibility Study OC 2012/PAD.

Source: World Bank[183]

Fig 82. Railway Projects Supported by the World Bank in China

The extensive HSR construction in China provides valueble construction experience to the Chinese railway builder: the 904 km Harbin-Dalian HSR line and 1776 km Lanzhou-Xinjiang HSR are all considered engineering wonders[184,185]. Many observers put the civil work expertise of China in railway construction,

[183] Gerald Olivier, Jitendra Sondhi and Nanyan Zhou, "High-speed railways in China: A look at construction costs", World Bank office (Beijing), *China Transport Topics*, No. 09, July 2014

[184] Harbin-Dalian is the world's first alpine high speed railway operating at high latitude and low temperature. The train route operates under a minimum of -40ºC to a maximum 40ºC temperature conditions at a maximum speed of 350km/h in summer and 250 km/h in winter

[185] The line is the first desert running HSR that goes through desert wind zone. It pass through 3607 altitude tunnel along the way and it is the highest operating HSR.

particularly in HSR construction, as the most significant comparative advantage it enjoys in global railway construction market. It is interesting to note that in the aborted 210 km Mexico-Queretaro HSR project, China was the sole bidder as the construction period of 2.5 year to 3 year will not be met by all other international competitors. Interest accumulated during construction is a major cost component for major infrastructure projects and the Chinese ability to materially shorten construction period is a major source of competitive advantage.

The second important cost advantage of China lies on its development of innovative and competitive capacity manufacturing of equipment[186]. Chinese rolling stock generally costs around one-half to two-third to that of international competitors[187]. Comparisons based on Figure 84 below on global system cost between 2009 and that of China on 2011. China's design fee and rolling stock cost is much lower than the comparative global standard. Apparently, the scale effect plus the innovation skills of the designers and equipment manufacturers are the main reasons behind the cost savings. China has managed to develop innovative and competitive capacity for manufacture of equipment[188].

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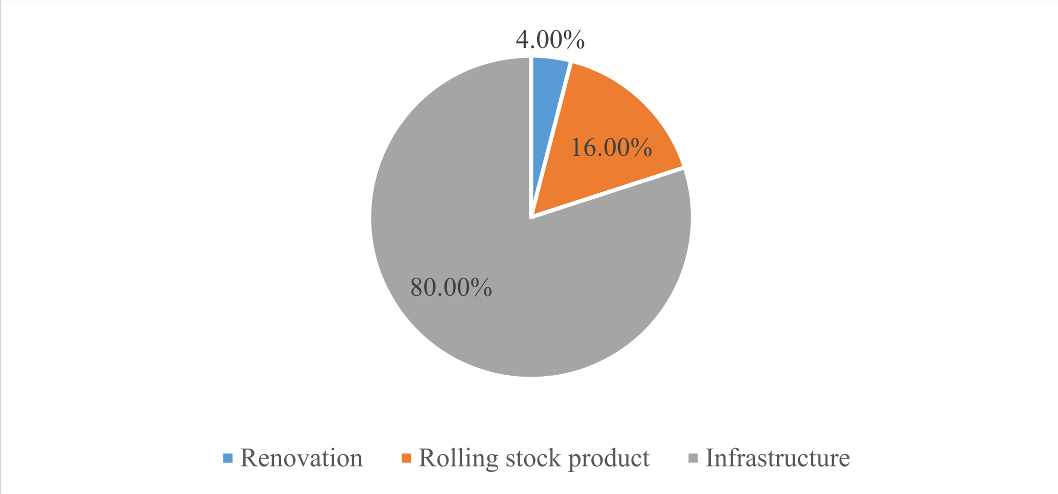
[186] Zhang Yu 张瑜，HSR promote local industries"高铁出海激浪环球大潮 国产化推进激发 6 股巨大空间"，中国证券报，19 December 2014, www.yicai.com/news/2014/12/4054254.html

[187] Jacqueline Li, "LT outlook positive; Buy CSR, new neutral CNR", *Rail equipment - China*, Bank of America Merrill Lynch, 21 October 2014

[188] Zhang Yu 张瑜，HSR promote local industries "高铁出海激浪环球大潮 国产化推进激发 6 股巨大空间"，中国证券报，19 December 2014



Source: UBS[189]

Fig 83. Breakdown of cost segments in HSR construction

During the 3rd quarter of 2015, China released a complete set of Technical Standard on the HSR. The standard puts China HSR as the fourth international HSR standard – on par with Germany's ICE, France's TGV and Japan's Shinkansen. The Chinese HSR system adopts the TGV and ICE systems, generally acknowledged to be more superior than the Shinkansen, in the area of electrical system. This adoption significantly improved the reliability of Chinese HSR. The Chinese standard also has a high degree of compatibility with TGV and ICE in terms of electrical system.

Various innovations in the Chinese HSR helped to build the Chinese HSR industry and firmly put it as one of the major contenders in the international HSR business. However, due to the large cost of investment, the Chinese HSR will continue to serve only the mainland market and remain as a domestic industry in the foreseeable future. Furthermore, the ideal choice of an independent HSR line is a transport corridor of less than 1000 km with annual passenger volume of around

[189] Xu, R. (2016). *China Construction-RMB 4.7 train transportation infrastructure construction plan for 2016-2018*. Manuscript, UBS, Hong Kong

10-20 million[190], and not many city pairs in the world fit the description. Although the EU certification standard is cumbersome and has a high barrier of entry, Europe is the biggest market for HSR and its spending on HSR equipment is even more than China's[191]. The prospect for the associated urban rail industry is much brighter- CRRC having won the Boston and Chicago subway railcar replacement in 2014 and 2016. The increasing urbanization and worsening urban traffic condition are favorable to the development of the urban rail system. In 2015, CRRC won close to USD 6 billion worth of export contract and it was the world's biggest rolling stock exporter since 2013[192].

Analysis of the Chinese HSR industry using the technological regime framework

To analyze the emergence of the Chinese HSR system, we developed the following model based on the neo-Schumpeterian technical regime.

Here, we used the four parameters of technical regime to analyze the Chinese HSR industry.

1. Opportunities (OPP)

The ccontinuously strong political and financial support from the government is a key factor behind the success of the HSR industry. The technical choice, standard setting, 2004 importation of foreign technology with local technology transfer and local manufacturing condition, as well as the formation of

[190] A new criterion for point to point distance is the travel time of four hours. At 300 km/h running speed, any two point that is 1200 km apart with sufficient passenger volume is ideal for HSR.
[191] CRC formed a partnership with Siemens in June, 2016 to work on joint bidding of HSR project.
[192] CRRC Annual Report 2015. (2016, April 27). Retrieved July 22, 2016, from http://www.hkexnews.hk/listedco/listconews/SEHK/2016/0427/LTN20160427686.p

a local research team between MOST and MOR, are all government policy initiatives which are critical in the successful localization of imported technology.

Of course, one should not overlook the policy risk of these government initiatives. The innovative government approach was successful because China has a capable and vast talent pool to learn and innovate. The HSR industry is a system-integration industry that draws on technology and knowhow from various areas of science and engineering. If not for the existing strong R&D capabilities already present in its rail sector, China is not likely to succeed. The successful adoption of foreign technologies and subsequent indigenous technological breakthrough builds up the Chinese HSR industry.

The international collaboration with leading countries, including Japan, France and Germany, also provided the Chines rail manufacturers with important opportunities to learn different HSR technologies[193].

2. Appropriability (APP)

The HSR industry is lead by the CRRC and most of the major companies in the industry are SOEs. The government's long term commitment provides the reward opportunity to these industry players.

3. Cumulativeness (CUM)

Before 2004, the failure of the development attempt of an indigenous high speed train taught Chinese engineers valuable lessons. This was corrected when they decided to import foreign technology in 2004 for their technology specification.

[193] The Chinese negotiator in the 2004 HSR technology importation remarked that China only spend around RMB 2.3-2.5 billion to get all the technology transfer agreement of the four trainset introduced to China. The HSR industry worldwide at that time is just recovering from the 2000 dotcom bubble.

Without a solid R&D base in rail technology, the unprecedented speed transition of Chinese train technology from 1G to 3G was unlikely to happen.

While China has succeeded in the HSR industry, its short history and lack of cumulativeness in certain areas in the industry is now being addressed in *Made in China 2025*. These areas are traction system control, traction motor, components, bogie and network control.

In contrary to other countries' experience of striving to setup new industries, the challenge of earlier accumulated knowledge does not seem to be critical in the case of China. The size of the existing industry as well as the presence of quality R&D personnel means China does possess a good degree of accumulated knowledge in virtually all industries.

4. Knowledge Base (BAS)

The HSR's train car and track are designed to run for 30 and 50 years respectively. With more than 12,000 mechanical parts in a train set and more than 1,000 sensors monitoring different functions in train operations, the industry is also highly system-integrated. The knowledge base in the industry is broad and varied, but at the same time, specified. The long life and delicate nature of the product imply that the entry barrier is exceptionally high, and a lot of complementary technologies are needed to put the innovation to use. Hence, it is not surprising to see only four major countries in the global HSR market, namely China, France, Germany and Japan.

Similar to cumulativeness in the technological regime, China's challenge on knowledge base is mute and the Chinese experience is contrary to conventional wisdom. As late as 2012, there is still much pessisism regarding the Chinese HSR industry. However, the presence of a huge R&D pool in various different knowledge field and the organizational power of the government to pull all the resources together to work out the indigenous technological are the two key factors in the building up of the HSR industry.

Alternative foreign technological acquisition route:

A fast catching up technological ascending country always faces increasing barrier in acquring new technologies from its former foreign technology provider. The model on technology and market development in figure 67 face a gap on the link between government policies and foreign source technology opprotunities under the circumstances. The critical choke point to the successful replication of the model in other industries under *Made in China 2025* is the technological learning opportunity from foreign source technology [194,195].

The alternatives to preserve the working of the model will come from increasing reliance on indigenous innovations that can meaningfully lessen the relative weight of foreign technology to complete learning opportunities on catching up/leapfrogging. At the same time, the country must develop alternative foreign technologies learning opportunity route from the vanishing cheap technology transfer agreement opportunities under the 2004/2005 HSR deals[196].

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[194] Rho, S., Lee, K., & Kim, S. (2015). Limited Catch-Up in China's Semiconductor Industry: A Sectoral Innovation System Perspective. *Millennial Asia, 6*(2), 1-29.

[195] Mu, Q., & He, X. (2012). How Chinese firms learn technology from transnational corporations: A comparison of the telecommunication and automobile industries. *Journal of Asian Economics, 23*, 270-287.

[196] The foreign suppliers are obviously caught by surprise on the speed of technology assimilation & innovation in the HSR industry. Italy, Spain, South Korea and Taiwan all introduce HSR to their rail system and they were only able to build component and assemble industry from the technology transfer, no one was able to build a meaningful complete industry up. These countries are supposedly more technological advance than China.

Earlier discussion at micro-level showed that China has developed the domestic industrial base which has a certain degree of technology accumulation and general knowledge base in other industries under *Made in China 2025* plan. China's increasingly indigenous R&D capacity based on the current 3.7 million R&D staffs has rapidly improved in quality, as witnessed by the unprecedented ascension of its nature index ranking [197]. China has a huge domestic market to support its appropriation of reward to innovators and the government has a proven long term view and execution power on industrial development[198].

At the moment, the most common routes for China to acquire advanced foreign source technological opportunities are through setting up of research laboratories overseas and merger & acquisition (M&A) of choice foreign technology company. For example, Huawei has set up ten overseas research laboratories. They had provided critical technology to their mother company in China. Geely's acquisition of Volvo and Midea's acquisition of Kuka are also notable successes. These new foreign source technology opportunities will plug the missing link in the model, and complete the innovation opportunity for the Chinese industries under *Made in China 2025*.

The increasing indigenous R&D human resources simply means that Chinese reliance on foreign technology acquisition as the primary method of technology advancement is decreasing and the country's technology acquisition is

[197] Leng, S. (2016, July 29). Science's rising stars: China's researchers make big leaps in contributions to top journals. Retrieved July 29, 2016, from http://www.scmp.com/news/china/article/1996154/sciences-rising-stars-chinas-researchers-make-big-leaps-contributions-top

[198] Kurlantzick, J. (2016). China's State Capitalism. In *State Capitalism* (pp. 93-114). New York, US: Oxford University Press.

increasingly domestic[199]. The biggest telecom company in the world, Huawei[200] is the most notable success story in this case.

Examining the model on technology and market innovation on HSR in China in figure 67 showed that the conditions necessary for the continuing working of the model in the other industries has not materially change with the development of alternative foreign technology route and increasing shifting of technology acquisition route from foreign source to domestic origination. The Chinese government appears to follow this development model when it set up the China Aero-Engine Corporation to speed up development of jet engine [201].

Summary of Findings at meso-level:

Analysis of the Chinese HSR industry's success using the 4 technological regime framework factors saw two critical elements behind the successful emergence of the industry. These two elements appear in the left column of the model and they are the initiating block in the model:

(1) Strong institution that can provide the political and financial support to build the industry and reward the innovators. In China's case, the government is the institution. In South Korea, it is a combination of chaebol and the government. In the west, it is private capitalists.

[199] The success of Huawei as the largest telecom company in the world shown the R&D ability of the indigenous researchers. The company only access foreign technology in its formative year by hiring former Shanghai Bell Laboratory employee to develop its first generation telephone exchange. All subsequent R&D are in-house.
[200] Fox, J. (2016, July 26). Huawei Conquers the World, Except the U.S. Retrieved July 29, 2016, from http://www.bloomberg.com/view/articles/2016-07-26/huawei-conquers-the-world-except-the-u-s
[201] China formed China Aero-Engine Corporation in July 2016 to address the delay in high power aero engine development. The company is akin to CRRC and was proven effective in the case of HSR industry development.

(2) Successful technological innovation requires a solid industry base and R&D capability. Cumulating specify industry level knowhow and building industry innovation capacity requires capable R&D talents. The more science-based the industry, the larger talent pool one needs.

The meso-level analysis demonstrates these two critical factors behind the success of the HSR model are intact at present. China has developed alternative routes to acquire foreign technologies and is increasing the contribution of domestic technologies in its industrial innovation effort. The effective HSR development model remain workable today despite the different economic conditions in mid-2000s and that of today.

Our findings indicated that the pre-conditions for the continuing working of the proven HSR innovation model based on neo-Schumpeterian analysis still exist today and China had demonstrated the ability to implement the model. Thus the country possesses the necessary pre-condition to succeed at the meso-level of neo-Schumpeterian Economics.

Chapter 6 - Research Findings at the macro-level of neo-Schumpeterian Analysis:

The role of government in economic development under neo-Schumpeterian Economics is extensive. It is expected to actively promote the national capacity building at micro-level, and formulate and implement industrial policy at the meso-level. While the micro-level national capacity building is one of the key universal economic functions of all government, the active involvement at industrial level is a distinguishing feature of neo-Schumpeterian Economics. In fact, the involvement at industrial development makes neo-Schumpeterian economics akin to the famous East Asian Model[202].

The involvement of government at the meso-level establishment of new industries focuses on two areas: The first area is to facilitate the technology learning opportunities and provide the initial appropriation incentives under the technological regime framework. The second area is to facilitate the appropriate linkages to solve the cumulativeness and knowledge base problems facing the nascent industry.

In the first area, the government often set up public research facilities, acquire advance foreign technologies, improve the imported technology and then localize them to help the players in the nascent industry. The government also promote the material incentives to the nascent industry by acting as their initial anchor customer and directly or indirectly channelling subsidies to keep the initially struggling new players in the industry.

[202] Lee, K. (2013). Introduction. In *Schumpeterian Analysis of Economic Catch-up* (pp. 3-24). Cambridge, UK: Cambridge.

In the second area, the government 's role in linking different technology sectors together to overcome obstacles facing the nascent industry in cumulativeness and knowledge base issues under technological regime framework had proven to be effective in building a new industry. The experience of HSR in the indigenous technological breakthrough that we recounted in chapter 5 highlights this point.

Introduction to Findings:

We will look at the technological learning curve traversed by China and then proceed to the elements that we will use in the macro-level analysis.

China's technological learning curve essentially follows that of other Asian countries'. At the beginning, it is concentrated on original equipment manufacturing (OEM), learning operational skills and processing technology from more advanced countries. It then moved to own design manufacturing (ODM), after developing certain in-house design skills. Now, it is trying to move into own brand manufacturing (OBM), with indigenous new product development capabilities[203].

What sets China apart from other Asian countries is the speed with which its technological learning curve is being shortened, and the scale at which this is happening.

Similar to other technological adoption mechanisms of the Asian tiger economies, China acquired foreign technologies from foreign direct investment (FDI), co-developed with foreign R&D specialist firms, set up overseas R&D posts

[203] Lee, K., (2005). Making a Technological Catch-Up: Barriers & Opportunities. *Asian Journal of chnological Innovation,* 13(27), 97-131.

to access foreign technologies, and joined the government-sponsored private-public R&D consortia to facilitate entry to new sectors[204].

To evaluate whether China possesses the pre-conditions to succeed in *Made in China 2025* at the macro-level of neo-Schumpeterian analysis, we examine the role that the government play in fostering the national capacity building at the micro-level and its activities at the meso-level in helping some nascent industries to overcome constraints imposed by technological regime.

Findings:

At the micro-level, the government effort on developing national innovation capacity is expanding.

The Chinese government had developed an indigenous R&D capability since its opening of 1978, and rapid expansion of R&D personnel and spending in the 21st century had contributed to the economic growth significantly. The continuing expansion of R&D capacity is notable and more results are expected down the road.

Year	Total	Government funds	Self-raised funds by enterprises	Foreign funds	Other funds
2004	196.6	52.4	129.1	2.5	12.6
2006	300.3	74.2	207.4	4.8	13.9
2008	461.6	108.9	331.1	5.7	15.8
2010	706.3	169.6	506.3	9.2	21.1
2011	868.7	188.3	642.1	11.6	26.7
2012	1,029.80	222.1	762.5	10	35.2
2013	1,184.70	250.1	883.8	10.6	40.3
2014	1,301.60	263.6	981.7	10.8	45.6

Data source*: China Statistical Yearbook on Science and Technology 2015.*

Fig 84. China's R&D Expenditure by Source (Billion yuan)

[204] Lee, K., (2013). How to build up technological capabilities. In *Schumpeterian Analysis of Economic Catch-up* (pp. 153-177). Cambridge University Press.

Year	Total	Basic Research	Applied Research	Product development
2000	922.1	79.6	219.6	622.8
2002	1,035.1	84.0	247.3	703.9
2004	1,152.6	110.7	278.6	763.3
2006	1,502.5	131.3	299.7	1,071.4
2008	1,965.4	154.0	289.4	1,522.0
2010	2,553.8	173.7	335.6	2,044.6
2011	2,882.9	193.2	352.8	2,337.3
2012	3,246.8	212.2	383.8	2,650.9
2013	3,532.8	223.2	395.6	2,914.0
2014	3,710.6	235.4	407.0	3,068.2

Data source*: China Statistical Yearbook on Science and Technology 2015.*

Fig 85. Full-time Equivalent of R&D Personnel (1,000 person-year)

The expanding effort on R&D had contributed meaningfully to economic growth.

	Average annual growth rate GDP	Contribution of Technological Progress (%)
1999-2004	9.2	42.2
2004-2009	10.6	48.4
2009-2014	8.5	54.2

Source: *China Statistical Yearbook on Science and Technology 2015.*

Fig 86. Contribution of Technological Progress to Economic Growth

In R&D, China draws favourable comparison now with developed countries. China looks like a developed country in terms of R&D power and does not resemble a developing country. A developing country normally spend less than 1% of GDP on R&D. The rate of increases in R&D spending as a percentage of GDP resembling the Japan experience in 1960s and 1970s, South Korea experience in 1980s and 1990s. The increase is a tell-tale sign of full fledge take-off in industrial innovations.

	China -2014	Germany -2013	Japan -2013	Korea -2012	UK -2013	US -2012
R&D Personnel						
R&D personnel (1,000 persons)	5,352	604.6	865.5	396	362.1	--
R&D personnel per 10,000 workers	69	143	134	160	121	--
% in Enterprise sector	78.1	62	67.5	71.1	45.8	--
% in government sector	10.1	16.2	7.1	8.3	4.7	--
% in higher education sector	9	21.8	24	19.5	47.9	--
% in other sectors	2.8	--	1.4	1.1	1.7	--
R&D Expenditure						
% of GDP	2.05	2.94	3.49	4.36	1.63	2.77
% financed by industry	75.4	67.8	75.5	74.7	46.5	59.1
% financed by government	20.3	14.7	17.3	23.8	27	30.8
% financed by other sources	4.3	17.5	7.2	1.4	26.5	10.1
Research Output						
Number of papers indexed by ESI*	1,369,834	900,112	804,677	389,181	805,372	34,543,554
Global Rank	2	3	5	12	4	1
Number of citations per paper	7.57	14.58	11.1	8.19	16.19	16.58

Source: *China Statistical Yearbook on Science and Technology 2015.*
Note: *reported are data from *Essential Science Indicators*, from January 2004 to April 2014.

Fig 87. International Comparison of R&D Activities

The Chinese government continues the political support to the science community. During the May 30, 2016 National Conference on Science and Technology (the second one in Chinese history that the meeting is held together with the biennial meeting of Academy of Science and Academy of Engineering), President Xi declared that innovation-driven development will be China's hallmark policy. He committed the country to concentrate human and financial resources on mission-oriented science and technology programmes such *Made in China 2025*. To him, the ability to pool resource is a particular advantage of China.

President Xi has announced a number of plans to build a more favourable working environment and a well-functioning ecosystem for innovation. The move will provide the software support for innovation, and complement the existing hardware resources that the government had set up[205]. The government had announced that developing the human resources and organization for implementing *Made in China 2025* is the first policy priority in the economic arena (人才领先). This policy announcement is similar to that of policy recommendation of neo-Schumpeterian Economics. Moreover, the commitment of the state provides the solid macro-foundation for success for *Made in China 2025* plan.

On the issue of industrial policy at meso-level, China had demonstrated outstanding skill on its formulation and implementation. The surge of Chinese economy has revived the interest on state capitalism. Many scholars had noted that the Chinese growth is not simply a result of its large and enterprising population. The success is also due to the careful economic strategy and its relatively forward looking, tough economic decision making government[206]. The success of the HSR model initiated by the government is a tangible proof of the industrial policy formulation and implementation capacity.

Our investigation shows that two factors stand out in the successful emergence of China's HSR industry. Firstly, a strong institution must be present to provide

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[205] Zhao, L. (n.d.). *China's Innovation-Driven Development Under Xi Jinping* (pp. 1-18, Rep. No. Background Brief).
[206] Kurlantzick, J. (2016). The State is Back in Business. In *State Capitalism* (pp. 1-26). New York, US: Oxford University Press.

financial support at the nascent stage, facilitate learning opportunities for foreign technology learning and local technology breakthroughs, as well as market access once foreign technology adoption happens. In the case of China's HSR industry, the institution is the Chinese government. Secondly, at the industry level, both indigenous technological breakthrough, or foreign technology assimilation and subsequent innovation over imported technology, depend on the technological capability of the existing indigenous firms in the industry and coordination of government on the linkages.

Aside from the traditional of cheap state funding, subsidized research, market support for selected industries under the industrial policy. China has some unique technological platforms that no other country has:

- Market for technology – the Chinese government has actively arranged business joint ventures with foreign multinationals and incorporated technological transfers into its joint venture agreements. This strategy is called *market for technology*. Though this strategy has not been entirely successful, there are cases in which it has worked and contributed significantly to China's advancement. The most notable example is high speed rail and telecommunication. The success or failure under *market for technology* is attributed to the technological absorptive capacity of the Chinese partner[207].
- Academic-centric forward engineering model - SIPO invention patent data shows that Chinese universities own 20% of invention patents. This is the

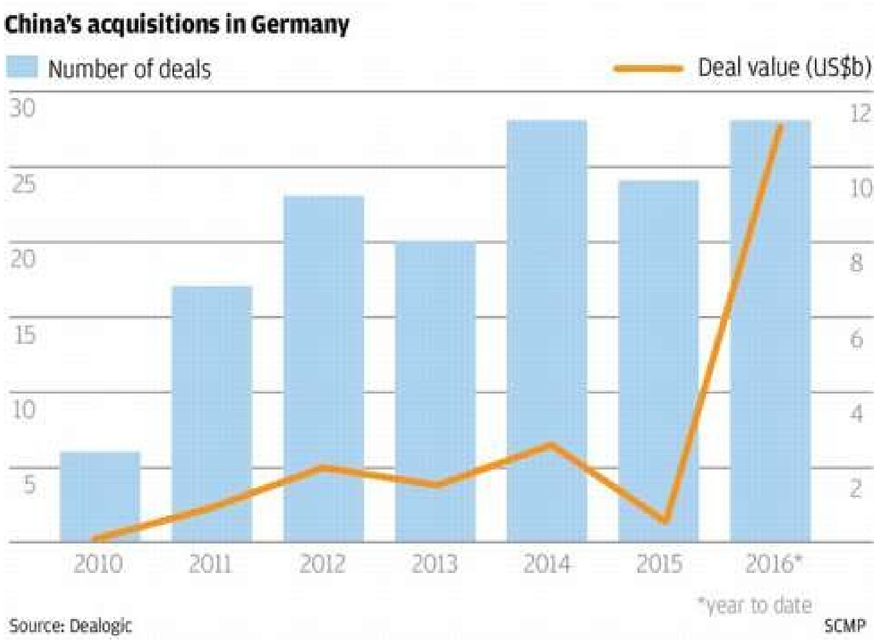
[207] Mu,Q., & He, X. (2012). How Chinese firms learn technology from transitional corporations: A comparison of the telecommunication and automobile industries. *Journal of Asian Economic, 23,* 270-287.

highest ratio of universities holding patents among major countries. Chinese universities have set up a number of national champions in many technological areas by exploiting their deep technological knowhow, e.g. Lenovo (computers), Founder (IT), Tsinghua Unigroup (semiconductor design), Dongruan (advance machine tools), and Siasun (robotics). These academy-run enterprises are widespread in China and important in many high-tech areas. They do not just do reverse engineering (a bottom-up process), but also forward engineering (a top-down process). In this model, particular academic institutions nurture and develop knowledge until it can be commercialized.

- Going global through international Mergers & Acquisitions (M&A) - Chinese companies have used this method to gain important technology. To name a few, China Railway Rolling Stock Corporation obtained its IGBT technology from its acquisition of UK's Dynex in 2008, and Geely's purchased Volvo in 2010. The M&A model to acquire technology is prevalent in developed countries, but is relatively rare for a developing country. This year, China stepped up overseas M&A in Germany to acquire technology in seven of the ten industries under *Made in China 2025*[208][209].

[208] Xie, Y. (2016, July 29). Midea emerges from the shadows with Kuka offer. Retrieved July 30, 2016, from http://www.scmp.com/business/companies/article/1996601/midea-emerges-shadows-kuka-offer

[209] Germany is a world leader in some key technologies in seven of the ten industries under Made in China 2025: Computerized numerical machine tools and robotics, aerospace & aeronautical equipment, maritime equipment and high tech. vessel, modern rail equipment, new energy vehicles and equipment, power equipment, agricultural equipment



Source: South China Morning Post[210]

<u>*Fig 88.* China 's acquisition in Germany</u>

The Chinese government is much more active today than ever before in the pushing of industrial policy. The *Made in China 2025* plan is a ten-year plan with specific technical target on many areas spill into 2030. This plan is running longer and much more detail on specifics than the customary five-year plan.

Made in China 2025:

Made in China 2025 is an industrial development plan with the following features:

- The *Made in China 2025 Technological Roadmap* (Green Book) is comprehensive and contains a fixed set of explicit technological targets. This is the basic point of reference when we look at how likely China can achieve its goals.

[210] Le Corre, P., & Sepulchre, A. (2016, July 15). Why China is investing heavily in Europe. Retrieved August 15, 2016, from http://www.scmp.com/comment/insight-opinion/article/1944491/why-china-investing-heavily-europe

- There are three timelines in the plan: 2020, 2025 and 2030. The technologies that China is more certain of normally run for two periods only: 2020 and 2025. Those that run for three periods are designed to provide more time for execution.
- The more detailed the technological roadmap, the more it indicates the drafters' confidence in the design of the plan.
- We should note that China excels in areas with very rapid technological turnover in the sense of most patent filings in that area, i.e. digital communication and computers. It is also strong in most of the electrical engineering areas but weak in the chemistry and mechanical engineering sectors. The technological innovation goal set in the plan is mostly catch-up "creative accumulation" rather than "creative destruction". Empirically, the slower technological turnover of the "creative accumulation" type industries are more favourable to determined new comers.
- The plan itself has several built-in mechanisms for success:
    - The plan is industry-based and is set by academics, industry experts, and the government. Targets are subjected to biannual review and set close to what the experts on the ground feel comfortable with. Take the case of semiconductor fabrication, an area where China is weak in and earlier attempts to accelerate innovations were not successful[211]. The target set for LSI fabrication is 20-14 nm technology in 2019-2025. Intel is fabricating its i-series chip today

[211] Rho, S., Lee, K., & Kim, S. (2015). Limited Catch-Up in China's Semiconductor Industry: A Sectoral Innovation System Perspective. *Millennial Asia, 6* (2), 1-29.

using 14nm Skylake microarchitecture, while Chinese technology is two to three generations behind.

  - The three timeline targets are multi-year and allow a high degree of flexibility. The targets for semiconductor fabrication are a good case in point, as they run from 2019-2025 for the adoption of 20-14 nm technology in LSI fabrication. In technological development, eureka moments are highly uncertain and setting flexible targets is a more realistic way of achieving the targets.

- *Made in China 2025* has set four broad targets for the economy. Their success will surely turn China into a more innovative, efficient, digitized and green economy. These generic targets are:

    1. On innovation:
        - Large scale manufacturers' R&D spending to increase from 0.95% in 2015 to 1.26% in 2020 and 1.68% in 2025.
        - Large scale manufacturers' patent numbers to increase from 0.44 per RMB 100m of sales in 2015 to 0.70 in 2020 and 1.10 in 2025.
    2. On efficiency:
        - Chinese manufacturers' competitive index to improve from 83.5 in 2015 to 84.5 in 2020 and 85.5 in 2025.
        - From 2015 to 2020 and 2015 to 2025, manufacturing value added (MVA) to increase by 2% and 4% respectively.

    The annual manufacturing productivity growth rate is set at 7.5% from 2016 to 2020, and 6.5% from 2021 to 2025.

3. On digitization:

   - Broadband national coverage to increase from 50% in 2015 to 70% in 2020 and 84% in 2025.
   - The application of Computer-aided design (CAD) tools to increase from 59% in 2015 to 72% in 2020 and 84% in 2025.
   - Digitization of key manufacturing processes is set at 50% in 2020 and 64% in 2025 compared to 33% in 2015.

4. On Green development:

   - Energy intensity per unit MVA to be cut by 18% in 2020 and 34% in 2025 compared to 2015 levels.
   - CO_2 emission per unit MVA to be cut by 22% in 2020 and 40% in 2025 as compared to 2015 levels.
   - Water consumption per unit MVA to be cut by 23% in 2020 and 41% in 2025 as compared to 2015 levels.
   - Industrial waste recovery to be raised to 73% in 2020 and 79% in 2025 as compared to 65% in 2015.

These targets cover all industries and in essence, turn the entire manufacturing sectors into innovation mode.

Summary of Findings at macro-level:

Our findings indicated that the government is still playing an active and important role on national capacity building at the micro-level. At the same time, it is playing an even more active industrial policy formulator and facilitator role with the *Made in China 2025* plan at the meso-level. The continuing active involvement of the government provides the necessary pre-conditions for success of *Made in China 2025* plan at the macro-level. The demonstrated ability of the Chinese government in running its industrial policy since the reform opening in 1978 under state capitalism model adds optimism to the fulfilment of the pre-condition[212].

[212] Kurlantzick, J. (2016). China's State Capitalism. In *State Capitalism* (pp. 93-114). New York, US: Oxford University Press.

Chapter 7 - Discussion

The dissertation looks at the research question- “Does China have the necessary pre-conditions for transformation into an innovation economy under its 4th Industrial Revolution plan? “. We posited that neo-Schumpeterian Economics provided the most suitable theoretical framework in the dissertation, over the conventional Solow model or the New Structural Economics. This argument of using neo-Schumpeterian economics in the Chinese context to address economic growth issues facing the country’s transition is novel and fills an important gap in the discipline.

Neo-Schumpeterian Economics looks at the innovation driven economic development at three levels. At the micro-level, it examines whether the country has built the national capacity of innovation and execution. The national capacity of innovation represents the human resources base, while the national capacity of innovation execution represents the entrepreneurship available on individual and corporate level.

The national capacity of innovation and execution are conceptual ideas under neo-Schumpeterian analysis. In the case of innovation capacity, the idea is operationalized by looking at tertiary enrolment, R&D personnel, R&D spending, quality of R&D research papers and the relative position of R&D output of China among global peers. In the case of execution ability, we look at the formation of new business, corporate size and patent activities. The specific technological breakthrough under the ten targeted industries in *Made in China 2025* program are a mixed bag of new technological breakthroughs and catch-ups, in fact, catch-up technologies represent the majority in the list. We analyse the standing of Chinese in the 35 technological fields under global PCT patent system.

The micro-level national capacity build-up is the most tedious step in the drive toward an innovation driven economy for any country. The effort takes time and persistence. The thesis findings indicated that China has already succeeded in building up a huge and diverse base in both industrial capacity and high-level human capital formation to drive an innovation-based economy. The process started right after the reform movement in late 1970s and early 1980s. It is initially gradual and uneventful, but the scale effect soon set in around early to mid-2000s. The findings at the micro-level show exponential type of growth in tertiary enrolment, R&D personnel, R&D research budget, R&D research paper output, indigenous business patent registration, rising ranking of Chinese patent and research paper among global peers starting around that period. While people noted the breakthrough of Chinese science and technologies one after the other in recent years, the foundation was actually laid decades ago[213].

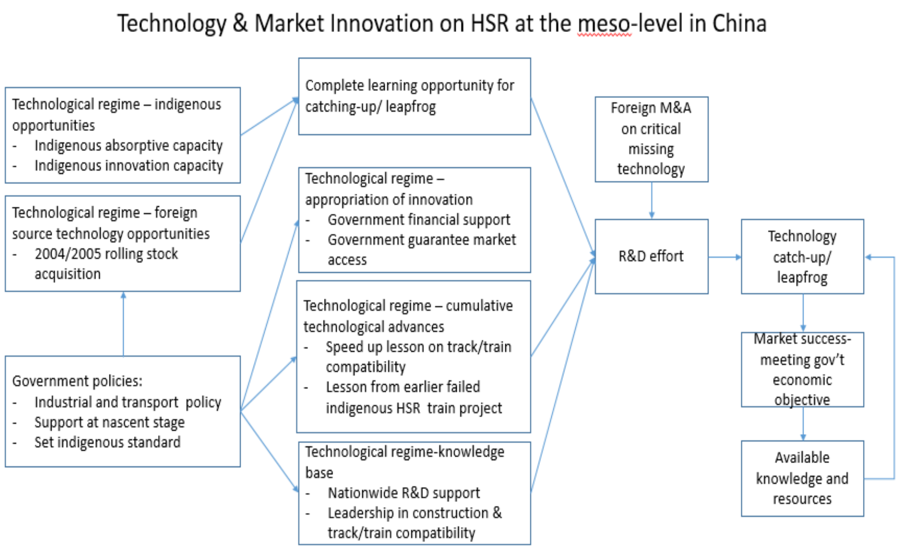
The successful build-up of national capacity on innovation provides the micro-level pre-condition to the success of China in its innovation drive under *Made in China 2025*. The national capacity is durable and persistent. It lays a solid foundation to efforts at meso-level and macro-level.

The second level of analysis is the industrial meso-level analysis. The meso-level is the monetization level of innovation and its success directly impacts the economy. Neo-Schumpeterian analysis uses the technological framework to look at the pre-conditions in setting up a successful new industry. The framework stated that four areas must be looked into and successfully resolved when a country wants

[213] Professor John Wong brought out this sudden upsurge of breakthrough from scale effect of a huge human capital base in one of his lecture to the author. The original idea came from the late Dr. Goh Keng Swee.

to setup new industry. These four areas are: First, how to acquire the learning opportunity to technologies in the new industry. Second, how to appropriate the necessary reward to keep the sustainability of the industry. Third, how important is the earlier accumulation of industry knowledge to the successful operation of the industry. Fourth, how many allied industries' knowhow and how critical are them to the industry's success.

We developed the following model based on the technological regime to explain the HSR industry's technology and market innovation at the meso-level.



Source: adopted from Mu[214] and modified by the author

Fig 89

Model on Technology and Market Innovation on HSR in China

[214] Mu, Q., & Lee, K. (2005). Knowledge diffusion, market segmentation and technological catch-up: The case of the telecommunication industry in *China Research Policy, 34*, 759-783. Retrieved April 25, 2016, from http://ac.els-cdn.com/S0048733305000946/1-s2.0-S0048733305000946-main.pdf?_tid=a799789e-0a97-11e6-bdf3-00000aacb361&acdnat=1461555895_22ed320f5c27866d3e3488f55519fddb

A look at the model immediately reveals the importance of two elements in the starting column of the model- the indigenous technological opportunities and government policy. These two boxes initiate all subsequent linkages and actions.

The HSR industry was selected in the thesis on following considerations: First, it is one of the industry under *Made in China 2025.* Second, it is an acknowledged success story on foreign technological adaptation story in China, as any successful business case is always an object of emulation. Third, the model that the thesis developed from the HSR experience remains valid today. It has good learning value and ready for adaptation in the other nine industrial sectors under *Made in China 2025.*

The findings indicated that there are two critical factors behind the success of the HSR industry setup: First is an enlightened institution that orchestrates all stakeholders to work together to overcome issues arising from the technological regime. Next is the available national capacity to absorb the initial foreign technology and then proceed to develop improved indigenous technology.

The thesis argued that these two critical factors behind the success of the HSR industry are present in the country today. Though we do not examine the other nine industries under *Made in China 2025*, we can induce by logical extension that the same government that acts as the enlightened institution to orchestrate HSR industrial development is the same one implementing the *Made in China 2025* plan. It is in good position to adjust the still valid winning model to use it in the other nine industries. The national capacity of innovation and execution is getting stronger as the scale effect of huge human capital base becoming more and more apparent. The thesis posited that China possesses the pre-condition at the meso-level to succeed in its innovation drive under *Made in China 2025*.

The third level of analysis is the government macro-level analysis. The government is expected to continue the active promotion of national capacity at micro-level and develop effective industrial policies at the meso-level. Analysis at this level is essentially examining the role of government in the innovation process of the country, looking at its past record and by logical extension, determine whether the country possesses the necessary pre-conditions to continue the success in striving toward an innovation driven economy.

The chapter on macro-level analysis indicated that the Chinese government is actively promoting the continuing build-up of national innovation and execution capacity at micro-level and actively pushing industrial policies through *Made in China 2025* plan. The country's success in this two areas is widely acclaimed and attested by its rapid economic growth and climbing up of industrial value chain. The country had alleviated more than 600 million people out of poverty in the last 37 years and the country is already the biggest country in terms of PPP GDP and marching to the biggest nominal GDP country in the next two decades[215]. The government has stated repeatedly that the industrial development model of China based on market signal and government leadership (市场指导， 政府引领) is the state economic policy.

The success of the Chinese industrial policy has revived interest on state capitalism. According to Council on Foreign Relation Senior Fellow, Joshua

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[215] Wong, J. (2016). Taking Stock of China's Past Economic Growth and Its Future Prospect. In *Zhu Rongji and China's Economic Take-off* (pp. 3-38). Imperial College Press.

Kurlantzick, “The Chinese growth is not a result of a country with a large population and entrepreneurial drives opening to the world. The growth is due to a significant measure to its careful economic strategy, its relatively efficient state capitalism combining economic strength and adaptability. The Chinese model could be a genuine challenge to free-market capitalism.[216]”

The demonstrated success of the Chinese government in their national capacity building and past industrial policies provide the logical extension to our assertion that China possesses the necessary pre-conditions to succeed at the macro-level under neo-Schumpeterian framework.

The three-level analysis clearly show their interlocking nature. The micro-level build-up of national capacity is a result of deliberate long term macro-level strategy. It takes decades and it is difficult to consistently implement on the ground. The success at the meso-level relies on the foundation provided by the micro-level factors and the orchestration at the macro-level. While the success at the macro-level depends on the continuing active state promotion at the micro-level and meso-level. The interplay of these three levels is dynamic and their coordinated success defines whether China can use innovation as the driver of economic development under *Made in China 2025*.

[216] Kurlantzick, J. (2016). A Greater Threat: State Capitalism's Long Term Effectiveness and State Capitalism as a Model. In *State Capitalism* (pp. 175-202). New York, US: Oxford University Press.

Chapter 8 – Conclusion:

Key findings:

The thesis affirmatively answers the research question, "Under its 4th Industrial Revolution plan, does China have the necessary pre-conditions to transform into an innovation-driven economy?". The thesis uses the three-level neo-Schumpeterian framework to analyse the pre-conditions and demonstrated that China does possess the necessary pre-conditions.

We have identified the necessary pre-conditions for *Made in China 2025* to transform the Chinese economy into an innovation-driven economy. These pre-conditions are: at the micro level: human capital; an entrepreneurial spirit; corporations that can provide entrepreneurship; innovation and execution capacities at the firm and industrial levels. At the meso-level: using the model developed under neo-Schumpeterian framework of technological regime, we look at whether China had the capacity to create entry opportunities for higher value-added activities in old industries and gain entry to new industries. At the macro level: examine whether the government has established a good record as an effective state capitalist that can continue to foster the elements at the micro and meso-level. The government's continuing active involvement at micro-level national capacity building and meso-level industrial policies formulation and implementation set the ground for innovations to succeed at the macro-level. These three levels interlock and they must work together in a systemic and coordinated way to deliver the innovations to transform the economy.

We have demonstrated that China has the pre-conditions to be successful in this transformation. At the micro-level, the thesis showed that China had successfully build-up the national capacity for continuing innovation at different disciplines. At the meso-level, we developed a model of innovation using the development case of Chinese high speed rail and argued by extension that the same successful model can also work in the other nine industries under the 4th Industrial Revolution plan. At the macro-level, we highlight the continuing participation of the government in building the national capacity and formulation of industrial policies.

The most challenging work in the three level neo-Schumpeterian analysis framework is the micro-level implementation. The success at this level takes decades of ground work and the scale is nationwide. However, once it is properly set in place, the national capacity provides the necessary foundation for the other two levels.

Research Limitations:

Economic development is a broad topic with many dynamic parts moving at the same time. This case is much more so in China, where the speed and scale of its economic development make any definite claim of knowing the true economic dynamics of China difficult. Our attempt to use basic neo-Schumpeterian Economics to understand China's 4th Industrial Revolution plan, *Made in China 2025*, is academically interesting and relevant. However, due to constraint in both data and methodology, our work is subjected to many limitations. We hope that our empirical neo-Schumpeterian Economics analysis will attract other scholars to work on the topic.

Future Research Recommendations:

Using neo-Schumpeterian framework provides an ex-ante lens to look at economic growth program, particularly for country that falls under Middle Income Trap. There are many research opportunities in this area.

1. The paper developed an industry development model and it can be used to assess the efficacy of many developing countries economic development program. Most of the countries' economic development programs are really industrial development program. They are often top down and use aggregate monetary parameters with little consideration to micro-level conditions and industry technology acquisition constraint. Our framework could be useful in doing an ex-ante assessment of such program.
2. Many developing countries face technological choice in their attempt to introduce new industries. Our industrial development model can be useful to work at the issue closely. This technological choice often determines whether a country can enjoy late-comer advantage and move into leapfrogging stage after foreign technology learning, or suffers from perennial late-comer disadvantages and always resign to catch-up role.
3. The paper determined two factors as critical in industrial catch-up and leapfrog: an effective organizational sponsor and a good micro-human resources foundation. They could serve as good guideposts to future studies of economic growth policy setup.

4. The role of innovation in driving growth is difficult to analyse due to both conceptual (presence of moderating factors) and data limitations. Most empirical works concentrate on the process of technological change, using quantitative inputs such as R&D investment, the number of researchers and assumed output such as number of patents and scientific publications. It is convenient to use regression to link input and output, but the relationship between both is probably more complicated. More study on the relationship of input and output on scientific innovation is needed.
5. OECD reports that four countries, namely the US, UK, Germany and China, account for 50-70% of high-impact publications across all scientific disciplines. These four countries' R&D spending accounts for 58% of the total spending of the top 40 countries in R&D. The positive relationship between R&D spending and output is without doubt. However, China built up its economy prior to becoming a research power house, and it took full advantage of its backwardness to adopt technology cheaply without expensive R&D. China's R&D budget broke 1% of GDP in 2000 and 2% of GDP in 2012. Its economy experienced booming growth in the 2000s. There are many studies pointing to the wastage of Chinese public R&D but few are insightful. This is a research area that could be relevant for many developing countries.
6. Neo-Schumpeterian analysis focuses on the mechanisms of growth in the real economy. It does not touch on the issue of monetary economics. Notable Schumpeterian economist, Horst Hanush had proposed more

studies on the relationship between the real economy, monetary economics and government fiscal policy[217]. This is certainly also an area worthy of exploring.

7. Neo-Schumpeterian Economics is a good tool to study the Chinese economy, as public policy plays an important role in it. We can look at the policy effect as the organizational innovation that triggers creative destruction or creative accumulation. How one can translate these organizational innovations into concrete capital accumulation --total factor productivity in the Solow model -- will be very relevant to policy design and monitoring. It is generally recognized today that neo-Schumpeterian Economics allows policy formulation but monitoring its impact takes time, as it is often side-tracked by noises from other economic events. Research to bridge the gap between the two school of thoughts can be important to policy makers.

8. We have demonstrated the necessary conditions for an innovation-driven economy under a Neo-Schumpeterian framework. This is the real side of the economy. However, stable macroeconomic fundamentals on the monetary side are also very important for the healthy development of the real economy. A volatile and unstable economy will suppress demand and eliminate market opportunities for innovation to benefit entrepreneurs. More research can be done on these monetary or macroeconomic constraints on innovation.

i[217] Hanusch, H., & Pyka A. (2007). Principles of Neo-Schumpeterian Economics. *Cambridge Journal of Economics, 31* (2007), 275-289.

9. Observations on the ground indicate that technological innovations are closely connected to an industry ecosystem rather than the earlier, simpler case of entrepreneurs and corporations[218]. This type of research is usually conducted in proprietary industry reports and is expensive to obtain. Open academic reports are rare, and this is definitely an area to look into.

[218] Berger, S., & MIT Task Force on Production in the Innovation Economy. (n.d.). *Making in America: From Innovation to Market.* MIT Press.

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