# Research and Development in China

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**Abstract**

In recent years, China has been more aggressive in its pursuit of developed countries. This includes vast investments in research and development (R&D). The paper studies current patterns of R&D in China and its impacts on Chinese economy as well as the world. We apply the theory of endogenous growth to explain the sharply growing intensity of R&D. Factors like market size, literacy rate, and proximity of other economies seem to play important role in earlier take-off of Chinese R&D. In the study of R&D, we take a detailed look at several important factors such as cultural background, human capital, and current policies. We also look for evidence: firstly in major sectors of Chinese innovation, secondly by study of patents and scientific papers, and lastly in comparison of experiences of China and South Korea. Finally, we elaborate on their impact on the R&D and on the future perspectives.

**Contents**



## 1. Introduction

Three decades of blistering growth has turned China into a prospering economy and one of the world super powers. Yet, the rapid growth didn't leave the country unmarked; deep problems including widespread pollution, corruption, threatening debt levels and a wide wealth gap might be a huge burden for the future China. In the midst of the economic reforms, growth is crucial for the country. China has been hastily pursuing growth like a bull following a red cape of a matador. For seven years up until 2011, China had an annual growth target of 8%. But how long can China sustain this astronomic expansion?

Robert Sollow was one of the first economists who identified new technology as the primary source of economic growth [41]. Technological progress and innovation are even nowadays heavily researched topics in economics. For instance, recent theory of economic complexity and complex technology is taking momentum [12]. It argues that more technology and know-how country accumulates, more it can benefit from accumulating new technology and know-how. Economists, for example, use the model to explain the deep differences between rich and poor countries [26].

Chinese leaders recognize the importance of innovation. Research and development (R&D) expenditures in 2012 reached almost 2% of China's GDP. That is staggering. While the investments in innovation are rapidly growing, the country has began the shift from producing low-quality goods to own high-technology products. With this trend, China's economic performance might ultimately depend upon its ability to acquire, adapt, and create new technologies.

We ventured to study R&D in China, mainly the reasons for increasing spending and its subsequent impacts on Chinese economy. Section 2 is devoted to evolution of innovation in China. At first, we study cultural background and its influences on innovation in China. The section also examines theoretical background. We try to determine what caused the early take-off of R&D investments in China. Section 3 tries to answer to what actually drives the growth and what are the recent trends. There, we take a look at current government policies, incentives to innovate, human capital, foreign R&D, and identify the priority sectors of innovation. Further, in Section 4 we compare experience of Korea and China in order to find empirical evidence and inspiration for apt policies. Finally, Section 5 tries to identify the future prospects and perspectives of R&D development in China. At the very end, we hint several policies based on our findings.

## 2. Evolution of innovation in China

### 2.1. Cultural influences on Chinese R&D

There are two systems of thought that have had the biggest impact on the institutions and cultural context of R&D in China. One is traditional Chinese culture and the other the soviet-style scientific institutions introduced shortly after the founding of the PRC.

Traditionally, there has been a great deal of reverence for knowledge in Chinese culture. Education and the studying of classical knowledge have been a means for social advancement ever since the official examinations of imperial China. Another key defining element for the Chinese approach towards the sciences has furthermore been the so called totalistic concept, wherein all things are connected through some sort of cosmical order. This has lead to a certain pre-disposition of trying to accommodate newly observed phenomena within existing frameworks and constantly trying to improve existing concepts, instead of creating new ones.

The pursuit of knowledge in China has also traditionally been rather utilitarian. Knowledge for knowledge's sake was rarely sought after, rather it was the practical use of the sciences and the constant improvement of existing inventions that were emphasized[13]. Another factor to be considered when discussing the Chinese approach towards research is the consensus driven nature of Chinese society as well as the social taboo of criticizing one's seniors which can severely hamper a young researchers ability to question flawed theorems and to propose innovative solutions. Altogether Chinese traditional culture seems to produce a certain ambivalence towards innovation, wherein traditional knowledge and the studying of proven systems are highly valued while the potentially disruptive effects of true innovation tend to be shunned [13].

The soviet inspired approach towards R&D that the PRC adopted can additionally be seen as a hindrance towards innovation. It tends to focus on large, nationalistic and potentially inefficient R&D projects, such as the Chinese space program. At the same time it is stifling individual researchers' scientific freedom. Knowledge is seen as a resource to be controlled by the state, not least because of it being a potential threat to the political system. In recent years, there has been a shift amongst China's R&D institutions towards more private sector involvement and more individual freedom which should benefit the country's

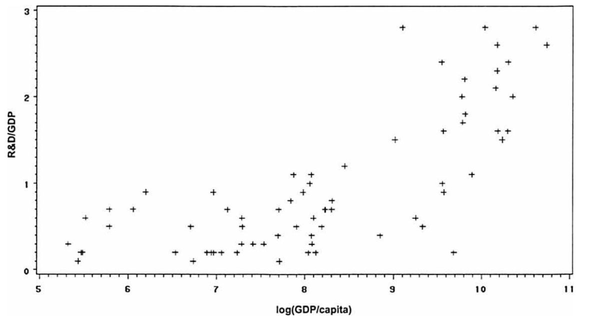


Figure 2.1: Scatter Plot for country observations R&D/GDP versus log (GDP/capita). Source: [22].

innovation capabilities. On the other hand the traditional ambivalence towards innovation mentioned earlier continues to exist and hampers China's ability to become a true world-wide innovation leader [13].

### 2.2. Take-off of Chinese R&D investments

The R&D intensity in China has increased drastically since the 1990s. In 1995 the level was only 0.57% of GDP while most recent statistic from 2012 show increase to 1.98% [31]. That is in fact above standard in the EU which spends 1.97% of GDP on average [31]. In this section we will examine the background of this surge in R&D activities.

Data from UNDP[45] reveal a strong correlation between log GDP and R&D intensity. For non-developed countries, the R&D intensity is around 0.7% while in the OECD countries the average is 2%. Further, it seems that levels of R&D intensity above 1% are observed in countries with a GDP per capita above $8,000 in PPP adjusted to 1999 dollars.

Gao and Jefferson [22], from now G&J, show that there is a general trend among OECD countries: When the annual R&D spending reaches 1% of GDP, an acceleration of the spending occurs, and within a decade the R&D intensity is around 2% or even higher. 2.1 illustrates the gap in R&D expenditures between countries below the $8,000 boundary and above. Additionally, larger countries (more than 45 million inhabitants) tend to increase their R&D intensity to a level between 2%-3%. Meanwhile smaller countries, on average, appear to plateau the R&D spending trend just below 2%.

From the theory on endogenous growth, G&J finds four conditions that give rise to R&D intensity relative to the entire output. They further test these theories against empirical work:

- *The factor income share of R&D labor rises in relation to that of production labor.* The demand and the subsequent production of intermediate goods rises relative to the general production of heavy industries in China. This results in increase in demand for human capital relative to unskilled labor. In China, this can be seen in a significant increase of technology-intensive production between 1995 and 2000 [22]; this has been ongoing trend.

- *As number of people working in R&D rises, the productivity of R&D labor improves.* The accumulation of knowledge and technology in the field of R&D increases the marginal productivity of the R&D labor. G&D find proof that by studying 5 major Chinese cities and Seoul.
- *An enlarged base of technological opportunity enables the rise of the scale effect of R&D activity.* Special economic zones and science parks, with high number number of high-tech companies along with significant FDI, give rise to knowledge spillovers. This knowledge can be transferred to the rest of the economy and thereby create scale effects. J&G don't find evidence of reverse engineering, but can show huge inflows of foreign technology and machinery.
- *Subsidies to R&D labor increase. This leads to rise in the productivity of R&D labor relative to the wages.* The increases in productivity for the R&D labor has not been followed by equivalent wage increases in China. Therefore, the companies have had an incentive to either hire more employees or invest equipment in the R&D sector. J&G point to the fact that the wage pressure in the traded goods section was very limiting. Employers did not find any incentive to adjust the wages of R&D workers. This, however, might be changing in recent years as there was a steep incline in wages China.

They further investigate the early acceleration of R&D intensity. In the case of China, unlike other countries with high R&D rates, the growth acceleration appeared early when GDP per capita PPP 1999 reached $3,600. That is well below the $8,000 found in the UNDP report [45]. Three key factors for this phenomenon are identified:

- *High literacy rates* – In 1999, China had relatively high literacy rate of 83,5%. This has caused that a growing demand for technology intensive goods and services. Especially, given initially relatively low level.
- *Market size* – Multinational companies in China has opportunity to build factories close to the source of growing demand in China. These production centers can gain from leaning-by-doing and learning-by-using in the local market. G&J sees this as a major reason for the higher observed level of R&D in countries with a large domestic market.
- *Proximity to dynamic economies* – The large amount of FDI coming from Taiwan, Hong Kong, Japan, Korea, and countries from South East Asia has brought a great deal of technology and know-how into China.

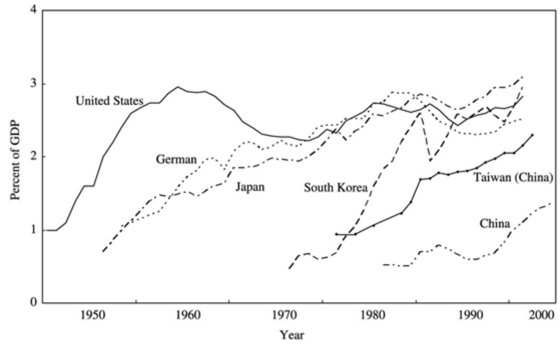


Figure 2.2: R&D spending in six economies, 1950-2004. Source: [22].

Finally, J&G study the factors that lead to plateau the R&D intensity:

- There will be an accelerated growth in technology intensity in the transition from producing low-tech to producing high-tech goods. When the transition is completed the technology growth will continue with the rate of growth of the technology itself. This rate is limited.
- The same happens with regard to human capital and physical infrastructure. Knowledge is quickly accumulated during the technology-adoption phase. However, at the top level of physical and human capital, it becomes harder to attain gains. One of the reasons is diminishing marginal productivity.
- The adoption of foreign technology will only last as long as the knowledge frontier converges toward international standards. The potential gain from adoption of foreign technology vanishes.
- The gap between wages and productivity closes, or at least narrows down.

In the endogenous growth theory, there is no equilibrium for the intensity of R&D since it is interdependent. The intensity of R&D is determined by government policies, human resources, economy growth. Meanwhile for example the quality of human resources also depends on intensity of R&D. In large OECD countries, the R&D investment fluctuates between 3 and 4%.

The ultimate question is whether Chinese R&D will keep growing in proportion to GDP and reach the top innovators like USA or Korea, or its R&D expenditures will plateau at the level of middle income countries. China does not seem to satisfy yet the factors for leveling off. Yet, the high growth in Chinese wages could be the first sign.

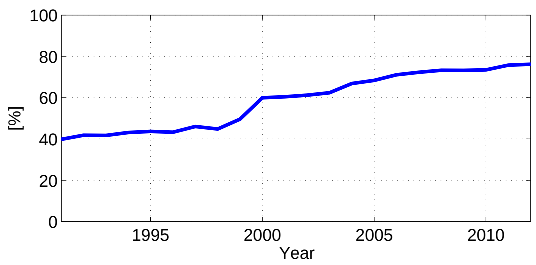


Figure 3.1: Percentage of GERD performed by the Business Enterprise sector. Data source: [31].

## 3. Recent trends in Chinese R&D

As discussed earlier, the rate of R&D spending in China has been staggering. In 2012, 1.98% of Chinese GDP was spent on R&D according to OECD [31]; that translates roughly to $160 billion. Considering the purchasing power, this makes China second biggest R&D spender right behind USA and far ahead of third Japan and fourth South Korea. Although impressive, this figure lags two years behind the Medium and Long Term Plan for S&T for the period 2006-2020 which envisaged 2% R&D spending by 2010.

In this part, we analyze the structure of Chinese R&D (Section 3.1). We separately look into R&D carried out by business enterprises (Section 3.2) and by public research institutes and universities (Section 3.3). In both sections we at first outlay government policies and their impact on R&D in respective fields. Secondly, we analyze the impact of increased R&D spending through a study of scientific papers and patents. Finally, the last section identifies the major sectors of innovation in China. We survey in detail Energy and ICT industries.

### *3.1. General overview of R&D expenditures*

The R&D structure of China is slightly different to the one of the second biggest spender, USA. Major part of R&D in China is funded by the corporate sector. In 2012, around 75% of Chinese R&D finances was from the purses of business enterprises. Meanwhile, the public spending on R&D (i.e. GovERD+HERD) accounted for around 23% of total R&D spending. From that, the cut for universities was only 33%. This is notably lower than in USA where government research institutes and universities carry significantly more research; their budget accounts almost for 42% of total US R&D expenditures. The high share of enterprise R&D is not typical for a socialist system.

The structure significantly shifted over time: in 1997 business R&D accounted for less than 45%. Figure 3.1 illustrates the phenomenon. That means 31 percentage points increase in 15 years.

R&D in China still stands more for development than for research. With the fast growth of R&D expenditures the share of funding going to basic and applied research significantly plunged from 30% of public R&D expenditures in 2005 to only 17% in 2010. This is considerably lower than in developed countries; median in OECD countries is 43% while in some countries like Switzerland or Slovakia it can be more than 70%.

The structure of R&D expenditures might suggest the strategy that China has pursued through the rapid increase of R&D in certain high tech sectors. The focus appears to be on the short term goals which are intended to quickly reduce the dependency of China on other countries in technology [17]. The question is whether they are going to achieve this through innovation or through imitation.

### *3.2. Business enterprise R&D*

As mentioned earlier, Chinese government consigns majority of the innovation to businesses. The increase in R&D spending raises a question about the driver of the motivation for companies to invest in R&D. This section outlays the government R&D incentives. Further it examines Chinese patents in order to study the impact of money spent on innovation.

#### *3.2.1. Government policies*

There are several kinds of government incentives which should motivate companies to invest in R&D.

There are three major types of tax incentives. First, a firm can be identified as a high and new technology enterprise (HNTE). For HNTE there is a reduction in corporate income tax (CIT) rate from 25% to 15% for three consecutive years. The condition are to incur sufficient R&D expenses (3-6%) in one of eight designated fields, engage more than 10% of employees in R&D, develop intellectual property (measured by number of patents) and transform it into products.

Second, super deduction translates into 150% tax deduction on qualified R&D expenses. Third, Chinese government also offers customs duty and VAT exemption for purchases of R&D equipment. Finally, there is a tax-exemption option on profits from technology transfer.

Besides that, companies can touch public funds through cooperation with universities and public research centers. In addition, in the attempt to create other “Silicon Valley”, China builds science parks where high technology industries are concentrated next to top universities. For instance, Zhongguancun in Beijing includes Peking and Tsinghua University, CAS, and 4,000 HNTEs [15].

Further, local governments often support local innovators.

In past, protecting domestic market using either tariffs of non-tariff barriers proved to be the major help which allowed Chinese companies to move up in the industrial chain. As we show later, it increased the motivation to innovate and increase its R&D funding.

One example might be the Chinese technical standards separate from the world standards. Also, for example Chinese Great Firewall may be regarded as a trade barrier in Internet industry.

#### 3.2.2. *Study of patents in China*

One of the important factors which motivates businesses and institutions to innovate is Intellectual Property (IP) protection and its main tool - patents [47]. Patents are often used by macroeconomists as an indicator of innovation [24]. State Intellectual Property Office in China (SIPO) was founded in 1980 and since then the number of patents filed every year has been raising exponentially. According to the data by WIPO, China surpassed USA in 2011 and Japan in 2012 in number of patent applications. In 2012 Chinese citizens filed worldwide more than 560 thousand patents [49], from that 95% (i.e. more than 530 thousand) were filed locally. There was around 480 thousand patents with Japanese origin and roughly 460 thousand with US origin. SIPO received 650 thousand patent applications in total; foreign patents were mainly from Japan, USA, and Germany.

*Quality of Chinese patents.* Yet, many question whether the quantity is followed by the quality, i.e. whether the patents are turned into something useful. To rate the quality of technology progress, OECD devised Patent Quality Index [34]. The index is based on the forward citations, backward citations, patent family size, number of claims, generality index, and grant lag. China ranked far behind average OECD countries, and even behind Brazil.

Further, as [36] points out, only 15% of all patents in force held by Chinese in China are invention patents. Then 48% are utility model patents (UMPs) and 37% design patents. UMP doesn't have to satisfy less strict requirements. In fact, there is significantly higher risk that a UMP is low quality [36].

[18] shows degrading overall quality of university patents.

*Patent policies.* In fact the policies should be blamed. They were obviously focused on quantity, not quality. Document "National Patent Development Strategy (2011-2020)" published by SIPO lays down broad economic objectives. Mainly, it targets two million patent filings by 2015. Other objective is to double number of patents filed in foreign countries.

Companies were rewarded for number of patents filed by tax incentives; further, individuals who file a patent can benefit from better housing and cash rewards[36]. Also some policies (e.g. HNTE) encouraged to use higher number of simpler UMPs instead of innovation patents [36].

The idea behind the policies is that large volumes of corporate patents will ultimately result in quality. [2] puts Huawei and ZTE as an example; focus of these companies was in the begging on getting a large volume of patents. But today, we can observe shift towards quality.

However, the situation in policies seems to be turning. China tries to tackle with the number of redundant UMPs. SIPO made small changes which should allow the examiners reject obviously uninnovative UMPs.

### 3.3. *Public research*

Over the past 35 years China has become one of the leading nations in science and technology. Government has significant role in steering the direction of public research. The section discusses how money are allocated among research institutes and researchers. Besides that, we study scientific publications to examine the impact of money invested to R&D by government.

#### 3.3.1. *Government policies to allocate funds*

Government runs several programs aiming to support big projects. For example, in 1986 program 863 was established to stimulate the development of advanced technologies. The program continues to play important role even today: for instance by funding R&D of space program or processor Loongson; see Section 3.6.2.

The major issue in scientific community on both institutional and national level is the fair allocation of funds, recognition of performance and achievements, obtaining academic titles, etc. This problem was even deeper in the early time of reforms when China suffered lack of excellent peers who could offer good peer review [21] and also cultural resistance towards assessment on the individual level [46].

Because of that, a concept of SCI papers was introduced in 1987. Nanjing University was the first to employ it to evaluate the scientific performance of individuals and departments[21]. Individual received a bonus for each paper which was published in a journal listed in Science Citation Index (SCI); at that time it was around a month salary. The university quickly improved its rankings nationwide. Thanks to the initial success, the system spread universally to the whole Chinese research community including CAS institutes.

There are several problems with this kind of ranking. Competition for funding increases pressure to publish more low-quality papers in the sense "publish or perish". Additionally, researchers rather choose research which brings results in short time. Moreover, since only the first author was rewarded, it decreased the incentive to cooperate. Finally, this kind of system attracts scientific misconduct[1]. Overall, it likely caused inflation in number of published scientific papers.

[1] Several recent major cases uncovered the problem of scientific misconduct in China to public. For instance, in 2009 Acta Crystallographica pulled out 70 papers co-authored by

The problem was recognized in 2003 by Ministry of Science and Technology. It encouraged employing citation numbers in the evaluation. Since then, top universities such as Beijing University, Fudan University, and Renmin University also adapted peer review. Yet, the legacy of SCI-papers based system is still remaining [21].

### 3.3.2. *Study of scientific papers*

Since 2006, China has dominated the world in the number of internationally-visible published papers (listed in SCIE). Only if we consider European Union as a whole, China would take second place [52]. The growth was exponential; there was only 1029 published in 1980 while in 2011 it was more than 150 thousand [20]. Scientific papers are an important pointer of scientific achievement and mirror the performance of the overall system [44]; citation counts have been used to asses the scientific impact [48].

However, [53] reports a slow down since 2010. It suggests that there might be a limit of growth in the number of researchers able to publish in international journals. The reason also might be that earlier in the past decade, the boom in quantity was caused when scientists shifted from publishing in national journals to international journals. Secondary reason might be the change in policies for fund allocation discussed above (Section 3.3.1).

*Quality of academic research.* Several outside studies were carried out over the past years to assess the quality of research in China [20, 29, 19]. They were mainly based on bibliometric statistics of scientific papers listed in SCI [48]. .

[21] uncovers that while the number of citations was growing, it was slower than the number of published papers mainly in period 1995-2006. That is illustrated in Figure 3.2. However, this gap has been recovering in recent years and China raced down developing countries like India. This might reflect the shift in policy of SCI-based rating. SCI-based ranking of individuals and institutions inflated number of publications while didn't motivate to emphasize quality and significance. Since 2003, institutions has been changing the policies so that they took into account even quality. Additionally, [21] found that on average Chinese papers are published in low-impact journals.

If we control for minimum number of papers to twelve most publishing countries, in 2012 China was on 11th

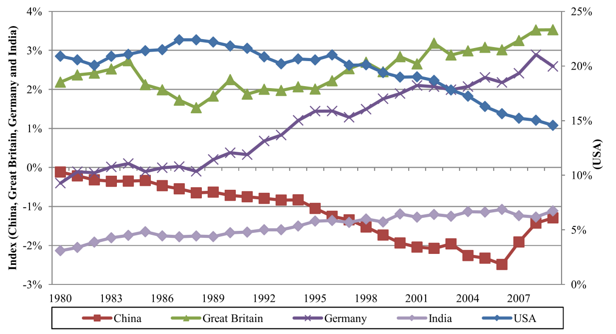


Figure 3.2: Comparison of share of citations and publications of selected five countries in the SCIE database. Share of published papers by respective countries is subtracted from the share of citations the papers generated. Source: **(author?)** [21].

place before India according to the rate of citations [40]. United Kingdom ranked as the best with rate 0.7 comparing to 0.27 for China and 0.26 for India. Using h-index (i.e. h of papers that achieved at least h citations) China would have ranked 16th worldwide in 2012 [40].

There is a number of positive accounts about increase in quality of top research. For example 4 out of 21 hottest researchers in 2012 were associated with Chinese institutions [35]. Also the number of papers from Chinese institutions in Nature, prominent interdisciplinary scientific journal focused on most important advances in science and engineering, grew by 35% from 2011 to 2012 [30].

In general, the study of scientific papers published by Chinese confirms that the quality of academic research in China is growing. Yet, the rate of growth is much smaller than the rate of the annual increase in number of publications.

### 3.4. *Human capital and education*

Highly educated human capital is a crucial resource required for innovation. Universities are not only big factories for papers, their major role is in education.

China's human capital base is growing in accelerated rate: in 2011 4.2 million students graduated in China, it was 650 thousand more than previous year. Important factor for R&D in China is significant share of Chinese students in engineering; in 2010 it was approximately 31% of all bachelor graduates [15]. Meanwhile, US institution awarded only 5% degrees in engineering during the same year. The attitude towards engineering is strongly rooted in Chinese culture. Further, S&E majors accounted roughly for 50% and 33% in China and USA respectively. This allows China to support rapidly expanding R&D sector and attract foreign R&D.

Besides the national education systems, China can also benefit from long tradition of foreign-educated students. First overseas students returned from the foreign universities in the 1880s. It plays a notable role in its development. In 2012, one out of four students in

two researchers at Jinggangshan university in southern China, because they had fabricated evidence [6]. Same year three professors from Zheijang University were suspended due to plagiarism [11]. Wuhan university estimated that in 2009 the whole industry of plagiarism was worth $150 million [6].

As a reaction, China has created an Office of Scientific Research Integrity Construction which should fight this problem. Recognizing the problem makes China an exception among the developing countries where the problem is significant [11].

the USA, the main destination for international students, was from China. However, Chinese students were most likely from other foreign students to stay after finishing their degree in 2009 [37]. Yet, this seems to change. Recent study shows that majority of students enrolled in 2011 expressed strong intention to return after finishing their studies [50]. Expanding economy and huge market in China can attract back not only students but also top academics. One-thousand-talents scheme launched in 2008 promises top salaries and high funding to lure back high profile academics. This had already its successes; for example, Tsinghua University recruited Shi Yigong from Princeton University [37].

In 1998, project 985 was introduced by the PRC to increase government funding into universities, and by extension towards research [51]. The excess funding is granted to the best ranked universities, it has therefore acted as an incentive for post-secondary institutions to improve.

Further, the 12th Five Year Plan stressed the need for the reform of higher education in science and technology. The government will soon start evaluating college majors by their employment rates, downsizing or cutting those studies in which the employment rate for graduates falls below 60% for two consecutive years.

### *3.5. Foreign R&D*

Foreign R&D in China has been a growing trend in the Chinese R&D sector. More and more foreign MNCs have established laboratories and research centers in China, mostly in the big coastal cities and government designated High Technology Development Zones (HT-DZs). According to Gassman and Han[23] there are several motivations for foreign companies to conduct at least part of their R&D activities in China:

- Availability of qualified personnel: China's university produce an abundance of highly qualified engineers and scientists every year.
- Informal networks: "GuanXi" is an essential part of doing business in China and through local R&D centers and cooperation with universities, these informal relationships can be established and nourished.
- Local pockets of information: Science parks and knowledge clusters purposefully established by the Chinese government attract foreign R&D activity.
- Customer and market-specific development: Adaptation of products to local tastes and standards becomes much easier for companies doing research in China. New ideas born in this different environment can also benefit the company globally.
- Cost advantage: R&D operations are in most cases much cheaper in China than in the USA for example. This is mainly due to lower wages but the Chinese government also tries to encourage foreign R&D inflow through monetary incentives such as duty-free import of equipment and tax incentives.
- Government policy: The Chinese government makes a coordinated effort to attract foreign R&D by establishing science parks, granting tax incentives etc. Prior to China's admission into the WTO, foreign companies were also often pressured to transfer technology in exchange for market share.
- Market size and growth: The sheer size of the Chinese market coupled with its continuing growth have played an important role in convincing foreign firms to conduct R&D operations in the country.
- Peer pressure: As more and more international firms conduct R&D in China, other firms are pressured into following suit for fear of competitive disadvantages.

### *3.6. Insights from major industries in China*

In the 12th five-year plan from 2010, Chinese leaders identified 7 major industries of interest: Energy conservation and environmental protection industries, ICT industry, Biotechnology industry, High-end equipment manufacturing, New Energy Industry, New material industry, New-energy automobile industry.

In this section we analyze in detail the recent trends in two of them: New energy industry and ICT industry.

#### *3.6.1. New energy industry*

China's massive population of over 1.3 billion poses a lot of challenges that the country must overcome. One of the main concerns is energy, and the resources required to sustain the high power demands China's needs. China predominantly relies on cheap natural resources, from which 60% comes from coal. China is expected to increase global demand for coal, projected to peak in 2020 with 25% of the world's coal consumption [4]. This form of energy causes a lot of pollution, and makes life in cities dangerous by doubling the region's carbon dioxide emissions. However, this does not undermine the commitment, China has, to renewable and alternate sources of energy. To be more specific, China's demand will increase to 0.61 billion tons in the next 6 years, which is unsustainable as the domestic supply accounts for only 29% of the energy needed. This offset results in dependence on foreign oil, making China's interest in alternative energy research more politically driven than it is environmental.

Switching forms of energy production is very gradual; it requires expertise, funding and government oversight. In order to achieve this, the Chinese government shifted focus in 2004 towards a clean and scientific approach to produce energy effectively and reduce pollution. Both the public and private sectors are established and involved in energy R&D. A plan was established for renewable energy to account for 15% of China's total demand by 2020. In the past few years, China started researching and investing in wind, nuclear and hydro-power sources. Channeling government funding to support these research initiatives is also being done through tax incentives. Biogas and wind power only have to pay 15% income tax while other sources range around 33% [33].

All of these alternative energy sources were already established in science prior to China's shift in policy, relatively little research was left to be done. Nonetheless, China is currently taking the lead in nuclear reactors that use thorium molten salt technology, the first of its kind in the world. A venture of this scale carries a lot of risk, both financially and environmentally. The first plant is said to open in 2020, and if proven successful it would drastically change China's energy program [16]. Thorium is abundant and cheaper than uranium; in theory the reactors should produce very little nuclear waste when compared to conventional plants.

### *3.6.2. ICT industry*

In those days, most people directly connect high-tech companies with ICT industry. Indeed, in recent years the biggest and most obvious changes directly influencing ordinary people arose from here. Moreover, development in ICT have direct impact on other fields ranging from manufacturing to education. Chinese leaders see the opportunity of ICT as an industry likely to become a new platform which could deliver growth and innovation. Additionally, recent research, e.g. in big data and smart cities, could help the government to tame problems like energy, pollution, or booming population.

China has the largest connected population: more than half a billion people have access to the Internet while there is more than a billion with mobile phones [7]. It grew roughly by 400 million only in last 4 years and thanks to the cheap smartphones and their penetration into rural areas the number is projected to grow in future. That is also what drives Chinese ICT industry: telecom operators and equipment corporations are among the global players and world leaders. Meanwhile, the research is becoming visible.

*Huawei.* Huawei, Chinese enterprise focusing on networking and telecommunications equipment and services, is one of the leaders of ICT industry in China. It was founded by Ren Zhengfei, a former member of PLA. He could take advantage of his experience and contacts in PLA, which was greatly interested in telecommunications during the time.

Huawei put emphasis on R&D from the very begging. In 1990, Huawei started to develop its own network technology, namely series of switches. Unlike Chinese competition, the decision was to do it in house; the decision turned out to be crucial for its future development [9]. At this time, Huawei had already 500 employees working in R&D while only 200 in production.

According to its official numbers, in 2012 it spent $4.8 billion in R&D. Huawei has 45% of its total workforce associated with R&D. In comparison, Ericsson spent comparable amount around $4.85 billion. Cisco, another big player from USA competing with Huawei mainly in networking, in 2012 spent $5.5 billion in R&D. Yet, thanks to the location of the R&D centers in China and India, Huawei have notable cost advantage when compared to the competition.

The focus on R&D has obviously payed off. Huawei can offer similar services as its peers for a fraction of price. In 2012 it took first place worldwide as a telecom supplier overcoming Ericsson [3]. However, the firm nowadays experiences friction due to security concerns as networks are becoming of national importance. For instance, Australia blocked Huawei's participation in building national broadband network [3].

*Lenovo.* Second dominant company in Chinese ICT is Lenovo. It was founded in 1984 by 11 engineers at the Chinese Academy of Sciences and is regarded as a pioneer of Chinese market reform in the technological sector. At first, it could only hardly compete with the foreign competitors. In its early stage it acted mainly as their sales and distribution representative for Chinese market. However, a clever move in 1996 when it significantly cut prices to almost zero margin and partnered directly with Intel allowed it to establish itself on the Chinese market neglected by the global players [10]. Growing Chinese market suddenly hungry for PCs (partly thanks to government support of IT purchases) gave it great kick.

Lenovo became known worldwide after its $1.75 billion purchase of IBM's Thinkpad PC business. The purchase of IBM came with leading PC R&D division.

In 2011 Lenovo spent $303 million on R&D. This amount is minute in comparison with HP; its R&D budget was in the same year more than $3 billion. Yet, even this small spending on R&D allows it to keep pace with the global players. Lenovo overtook HP as the top PC vendor last year [5]. Meanwhile, recent purchase of Motorola shows that its focus is shifting towards mobile.

It is good to note that Lenovo didn't achieve the success through any major technological break-through but rather through sensitive adaptation of innovation to the market [10]. This aligns with the attitude towards innovation which we discussed earlier.

*Loongson.* While Chinese companies dominate telecommunication and PC markets, China is still not self-sufficient in the area of microprocessors. This field is dominated by companies like Intel or AMD. For example, China's pride Tianhe 2, world's fastest supercomputer, still runs on Intel processors. That also applies to ubiquitous ordinary PCs in Chinese administration.

Processors today are the core part of most electronics - from toys, through washing machines, smart phones, routers, rockets, cars to super computers. Further, lack of own microprocessors technology appears to be the main obstacle to indigenize information technology in China. Today, China is forced to excessively rely on services of Intel and Microsoft [43].

With support of government from the Project 863, Loongson emerged to solve this problem. Loongson is a family of processors developed in a partnership between chip designer BLX IC Design Corp. and the Chinese Academy of Sciences since 2001. The first commercial version is planned for this year and might be used by several provincial governments and in servers [1]. Despite immaturity of the project, China's Haier and Hisense already incorporated the embedded version in their televisions [43].

Loongson will have hard time to make its way to our computers. Nonetheless, with the government supporting a demand for initially immature versions of the processor through government institution, the processor could be soon powering millions of PCs. Loongson is a great example of how Chinese government can sway and support Chinese high-tech industry using huge domestic market.

## 4. Empirical evidence from Korea

After Korean war, South Korea lacked own technological resources. Yet, today Korea is considered as one world leaders in high technology. Korea achieved amazing economic development, so-called "Miracle on the Han river". This sections tries to compare the experience of increasing R&D expenditures in South Korea and China. We try to show the close relation between the GDP growth and growth of R&D investment.

In the beginning of industrialization, during 1960s and 1970s, export-directed policies by Korean government stimulated public and private sectors. Like today's China, to make use of the cheap labor, Korean government pursued export-directed strategy. The problem was the lack of own technologies as well as experience to develop them. Therefore, in the first stage, Korea inevitably depended on technologies from abroad. Similarly to China, Korea tried to internalize technologies by imitation and learning. Later, this turned out to be an important stepping stone to move towards more sophisticated technologies.

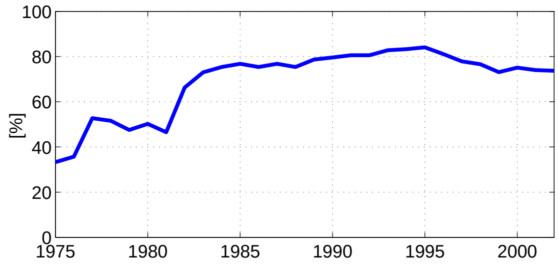


Figure 4.1: Share of privately financed R&D in Korea. Data source: [42].

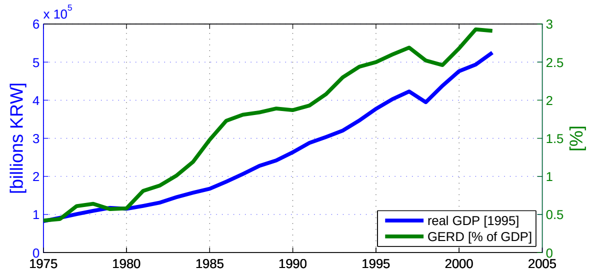


Figure 4.2: Real GDP of South Korea in billions KRW and GERD as percentage of GDP. Data source: [42].

Later, during 1980s and 1990s, more foreign companies became alerted by Korean successes. In an attempt to decrease the dependency on foreign technologies, Korean government reinforced many policies to indigenize R&D. In this period, investment mainly focused on heavy industry. Year 1982 was an important milestone in Korean R&D. Government established National R&D program with narrow focus on specific areas of industry. Further, government began promoting private firms' research through financial and tax incentives. This reflected in sharp increase in enterprise spending on R&D; see Figure 4.1.

Since then the importance of private sector in Korean R&D has increased. The innovation was driven mainly by corporations like Samsung, LG and Hyundai. In recent years, one of the important factors for Korean industry was the boom of IT. Investments in R&D helped to finally reach the competitive level of other developed countries. Today, South Korea invests around 3% of GDP in R&D [31]. It has 7th largest R&D budget among other countries. Also, the output of R&D is notable. For example, cutting edge electronics such as notebooks and smart phones of Korean companies like Samsung are perceived very high by consumers.

According to [39], contribution of R&D to the economic growth rate has been quite significant. In periods 1971-1989, 1990-2004, and 1971-2004, the contribution is estimated to be 23.3%, 30.4%, and 30.6% respectively. Considering the level of economy in 1960s and the scale between USA, Japan and South Korea, the impact of R&D on the economic growth is notable. Without any doubt, R&D played a great role for the amazing economic performance of Korea; see Figure 4.3.

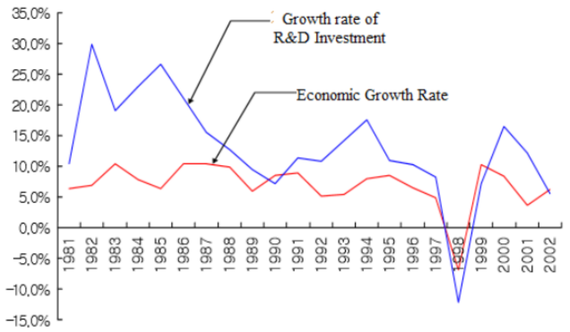


Figure 4.3: Correlation between the growth rate and rate of R&D investment. Source: [42].

There were several keys to the success. First of all, the educated human capital allowed efficient absorption of the new knowledge. Although the economic indicators were far below the average, the enthusiasm for education has been significant and widespread. This stimulated Korea to commence the growth. Additionally, active government support contributed to the achievements. As mentioned above, Korean government used both direct investment and incentives to grow roots for the future R&D. For example, institutions and R&D complex in Daejeon were established. Additionally, indirect investment such as tax benefits and low interest rates for funding R&D stimulated the private sector to invest in R&D. All these efforts enabled Korea to improve the technological level. That, in consequence, resulted in rapid economic development.

As shown above, there are many similarities between the experience of South Korea and China. Both economies focused on labor-intensive industry and export-directed strategy in the early stage of industrialization. After that, they moved to heavy industry and IT sector with higher added value.

However, there are some differences in terms of socioeconomic conditions. Importantly, political situation in both countries is different. While Korea has built its democracy, PRC is in essence a socialist system. This involves different political power and relationship between the government and multinational technology companies. Secondly, due to the territory size, the impact of the domestic market is substantially different. Also, unlike single-raced Korea, huge territory of China means widely diverse population. This might be one of the obstacles; it is likely to generate conflicts and additional costs for China in the future. Additionally, even though Chinese education is on high level, it is limited only to a portion of population. For example, literacy in Korea increased from 87.6% to 93% only in two decades between 1970 and 1990 [38]. Meanwhile, China is still struggling with high rate of public illiteracy.

Chinese policy-makers are tempted to emulate past Korean technology and industrial policies. Nonetheless, the policies and their effectiveness eventually end up being very different due to the different political as well as economic environment. Despite that, China should make best of the Korean experience. They must compare specific situations and then selectively apply key successful factors.

## 5. Future perspectives

China's government released the "National Medium- and Long-term Program for Science and Technology Development" in 2006. In it, China set a goal to increase R&D investment to 2.5% of GDP by 2020. Additionally, government targets 60 percent of economic growth coming from technological progress. By 2020, China wants be the fifth in the world for patents and publication citations worldwide [28]. Besides that, the Twelfth five-year plan (2011-2015) states that spending on R&D should increase to 2.2% by the end of 2015 [27]. As mentioned in previous sections, in 2012 China spent 1.98% of GDP in R&D; they already lag behind.

Given these plans and programs, it is clear that China focuses on improving its position in innovation in the world. To reach the goal, several policies has been in : For instance, IP rights have been upgraded, or incentives for R&D investments have been introduced in national and local levels. These policies primarily consist of tax based incentives. This has caused a rapid growth in the number of R&D centers by multinational companies and the number continues to rise [27]. Besides that, the purchasing power of China is enormous and follow growing trend of GDP. It provides a reason for companies to invest in R&D in China. Because of these reasons, R&D investments and FDIs are expected to grow for many years to come.

The plans for increasing the R&D investments in China are clear. But, are the government officials doing enough to succeed in those plans? And more precisely, are those plans correct? Can China provide sufficient education to sustain the R&D growth? There are always obstacles when the goal is ambitious.

If China wants to keep increasing the R&D investment rate, it should keep the economy growing to keep the environment positive for companies. We showed strong correlation between growth of R&D expenditures and GDP growth in Section 4. Nonetheless, data from [14] show that recent GDP growth of PRC has been slower than expected. The targets were reduced from 7.7 % GDP growth in 2013 to 7.5 % in 2014. It is, however, partly intended; China is driving the economy towards growth driven by domestic demand.

The goal to increase the number of patents has led to massive growth in number. However, as we showed in Section 3.2, the quality of the patents is sometimes questionable. Former president of Google China pointed out that innovation in China nowadays is "borrowing an existing idea and tweaking it for the Chinese market." For example, only 1.2% of patents granted by European Patent Office came from China-based inventors, compared to 19.6% that of Japan [25].

Next important issue is the fair distribution of public funds. As section 3.3 discussed, academics are judged on the number of publications they publish and the amount of funding they receive. The value of professional network is often more important than the quality of the research [25]. This penetrates even to funding of R&D in business sector.

Universities has been expanding through funding from projects 211 and 985 [8]. Only last year, there was around 7 million university graduates, large portion of them received engineering degrees. China might also benefit from attracting big amount of overseas students and academics. See Section 3.4. All this should support future R&D expansion and even drive the future of R&D forward. Yet, the obstacle here might be role of culture and the education style. It encourages rote learning over creative thinking. Together with the approach of Chinese towards innovation (Section 2.1), this can cause lack of original innovation.

In the future, China might want to focus more on the quality rather than quantity only. The question is whether the quantity will eventually lead to quality. We feel that the intentions are to help rapid building of "infrastructure" for the innovation. Yet, there is a lack of evidence from the real world to support this strategy.

Based on the issues and obstacles presented in this paper together with OECD report [32], we tried to identify several directions the policy makers might consider:

- Rebalancing public and private R&D. China should build on strengths of its public research and not only focus on development of high-technology industries. China also shouldn't recklessly pursue development solely few major fields. Chinese government should act more in the areas of systemic failures.
- Strengthening the evaluation culture on public and enterprise level. Fight with corruption and scientific misconduct. Promote quality for in
- Better coordination of national and regional initiatives to increase R&D investments.
- Improving corporate governance to increase R&D spending.
- Improve the enforcement of IP rights protection. Encourage competition in innovation.
- Promoting R&D in public.

With emphasis on the areas mentioned above, provided a stable GDP growth, Chinese R&D has a chance to keep rising in the future. Yet, it might not be able to reach the ambitious plans so quickly.

## 6. Conclusion

World is changing in an extraordinary rate. Not a long time ago, we described China as the factory of the world. China has mobilized resources for science and technology on an unprecedented scale and in very short time. Today, it is a major R&D spender and it was able to overcome many obstacles during past years.

Theoretical work and experience from other countries suggest that once China reaches the top level, it will be very hard to keep R&D investments growing. Nonetheless, China has many unique parameters like incomparably larger market and vast pool of human resources which might yield completely unique experience.

China has still a lot to improve and many obstacles to overcome in order to become the world S&T leader. Major part of the effort today is directed towards catching up with the developed countries. The trend was to shift from public laboratories to the enterprises. Chinese leaders must be careful when designing the policies and not forget the importance of basic and applied research from which Chinese companies like Huawei or Lenovo benefited in the early stage. China also must deal with its past and use it as an advantage rather than an anchor.

Inflated number of patents and scientific papers suggest that part of the R&D growth in past might have been partly only artificial and a result of bad policies. Yet, the money might not be completely wasted as this may be a way to build R&D "infrastructure" from which the country can benefit in the future. The ultimate question is whether this will eventually lead to quality.

There are mainly great prospects for the future. Without any doubt, China's emergence as an innovator will have deep impacts on the world economy. There is a massive pool of talent which only begun to be tapped. It will bring more intense competition in the production and application of new knowledge.

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