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CWPE 1447

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EPRG Working Paper 1421

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Keywords China, R&D, science and technology, spillovers, imported technology contracts

JEL Classification I23, I28, O31, O32, O38, N35, N75

Contact dabo.guan@uea.ac.uk
Publication December 2014
Financial Support European Commission FP6 TOCSIN project, AXA Fellowship, Chinese Academy of Sciences (71250110083), Italy's Ministry for Environment, Land and Sea (ZL)

China's road to a global scientific powerhouse

Dabo Guan[1,2,3]*, David M. Reiner[4], Zhu Liu[5,6,7]

[1] School of International Development, University of East Anglia, Norwich, NR4 7TJ, UK
[2] Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, 110016, China
[3] St Edmund's College, University of Cambridge, Cambridge, CB3 0BN, UK
[4] Energy Policy Research Group, Judge Business School, University of Cambridge, Cambridge, CB2 1AG, UK
[5] Mossavar-Rahmani Center for Business and Government, Kennedy School of Government, Harvard University, Cambridge, Massachusetts 02138, United States
[6] Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University, Cambridge, Massachusetts 02138, United States
[7] University of Chinese Academy of Sciences, Beijing 100049, China

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* Corresponding author details:
Email: dabo.guan@uea.ac.uk
Telephone: +44 (0) 1603 592337
Fax: +44 (0) 01603 451999

Other Authors' details:
David M. Reiner: d.reiner@jbs.cam.ac.uk
Zhu Liu: zhu_liu@hks.harvard.edu

1. Introduction

Even as R&D budgets in the leading advanced economies in the EU, Japan and US are stagnating or growing slowly in the wake of slow economic growth, China's rapid growth in research and development (R&D), academic publications and patents has led the OECD to project that China will become the global leader in R&D funding before 2020 [1]. Whereas annual growth in R&D spending among OECD countries fell to only 1.6% over 2008-12, half the rate of 2001-2008, Chinese spending doubled over that same period. By 2012, China's gross domestic expenditure on R&D (GERD) was $257 billion, third globally behind the U.S. at $397 billion and the E.U. at $282 billion, but already well ahead of Japan's $134 billion [1].

Yet in spite of the dramatic increases in resources, there remains significant concerns that, at its core, China's innovation system relies too heavily on foreign technology and is 'underperforming', with little evidence of research translating into innovation, in part because of a longstanding disconnect between research and industry. [2] To create a system of institutions needed to organise and oversee the university-industry-government research complex, the Chinese government initiated a number of major science and technology programs to encourage economic development, the largest being the Gong Guan, 863, and 973 programs [10]. Within less than a decade there has been a transformation of university research and academic publication records driven by academic researchers reacting to incentives to publish in leading international journals.

Yet these impressive successes also cover up a number of serious underlying problems: there is little effective coordination across higher-level agencies, too often funding is allocated to scientists via connections with government officials (*guanxi*) rather than via a fair, transparent peer review process and individual incentives suffer from a weak performance evaluation culture, thereby encouraging numerous rent-seeking opportunities [2].

The phenomenon of China's effort to catch up with nations that are historically far ahead not only in terms of economic growth, but also in terms of its innovation systems falls into the wider literature on 'catching up' led by Chris Freeman, Luc Soete and Richard Nelson [3,4,5,6,7,8,9]. This research is driven by a desire to test the optimistic claims that countries that are catching up will be able to take advantage of the past experience of leading countries, which will allow historically laggard countries to catch up quite rapidly. The central question is therefore how best to accomplish this catching up and what role foreign investment can play in the process.

Xiaolan Fu and others have investigated the interrelationship of foreign investment and research activities [6,7]. These studies find that "the benefits of international technology diffusion can only be delivered with parallel indigenous innovation efforts and the presence of modern institutional and governance structures and conducive innovation systems." [7] Fu and Gong [8] also find that whereas Chinese firms have taken the lead in low- and medium-technology industries, foreign firms dominate in the high-technology sector. Although foreign investment is shown to contribute to the capabilities of Chinese industry, R&D activities of foreign-invested firms are also found to have exerted a significant negative effect on technical change of local firms. A related issue is how appropriate technology developed in leading industrialised countries is for emerging economies and the extent to which more effort should be put in to developing domestic technological innovation. To what extent does foreign investment in technology complement indigenous innovation efforts?

Finally, the energy sector and energy technologies in particular have become a national priority over the past few years and play a lead role in the innovation system [8]. Foreign firms and foreign technology contracts have played a key role in the development of the industry and has been critical to the development of advanced and low-carbon technologies in particular and so serves as an excellent testbed for studies of catching up. For example, in the case of Chinese wind turbines, so-called technology upgrading (as measured by increasing turbine size) and catch-up (as measured by reduced distance to global leaders in turbine size), studies have found government policies to be significant for technology upgrading but not catch-up [9]. More generally, what role does foreign investment and technology contracts play in the energy sector?

The remainder of our analysis is divided into five sections: a review of the current state of Chinese R&D systems, an analysis of the Drivers: economic prerequisites vs. policy implementation a review of the patterns of investment in Chinese domestic R&D, China's international technology spillovers in the form of imported technology contracts, followed by some conclusions.

2. Catching up with the 'North': The State of China's R&D Systems

When China embarked on its market-oriented economic reforms at the beginning of the 1980s, its science and technology system faced far-reaching challenges arising from pervasive inefficiencies, R&D weaknesses, poor technical skills and an almost-exclusive focus on defence and other heavy technologies [11]. Prior to the 1990s, Chinese annual R&D investment accounted for less than 0.3% of total gross domestic production (GDP). Over the past three decades, the Chinese economy has grown to become the world's second largest, and now China is one of the major manufacturing hubs, ranking as the second largest exporter in the world [12].

At the same time, China has dramatically enlarged the scale of its R&D investments. During the 1990s, China's goal was to be among the top 10 most S&T-competitive nations by 2010 [13]. However by 2005, China already achieved the sixth largest R&D expenditures in the world amounting to US$29.9 billion (in 2005$) [14]. Between 2005 and 2011, that figure increased three-fold to 113 billion US dollars, amounting to 1.8% of GDP [15]. Thus, within a decade, China has overtaken many western countries in terms of annual R&D investment, as shown in Figure 1. China now ranks second after the US in terms of R&D expenditures (and not far behind the European Union taken as a single unit). Further, China has the world's second largest stock of R&D personnel, including both researchers and support staff. In 2010, there were 2.5 million researchers in China, which is 44% more than the US and three times that of Japan. China is also leading the world in the number of PhDs produced, with 117,000 graduates in 2010, a ten-fold increase over 1990 [16]. The share of Chinese universities graduates with degrees in science and engineering is 39.2%, almost twice the OECD average [17]. Compared with other major transition countries, Chinese annual R&D investment was about six-fold that of Russia (17 billion dollars) in 2010 and Brazil (18.5 billion dollars) in 2009 and 17 times bigger than India (6 billion dollars) in 2008.

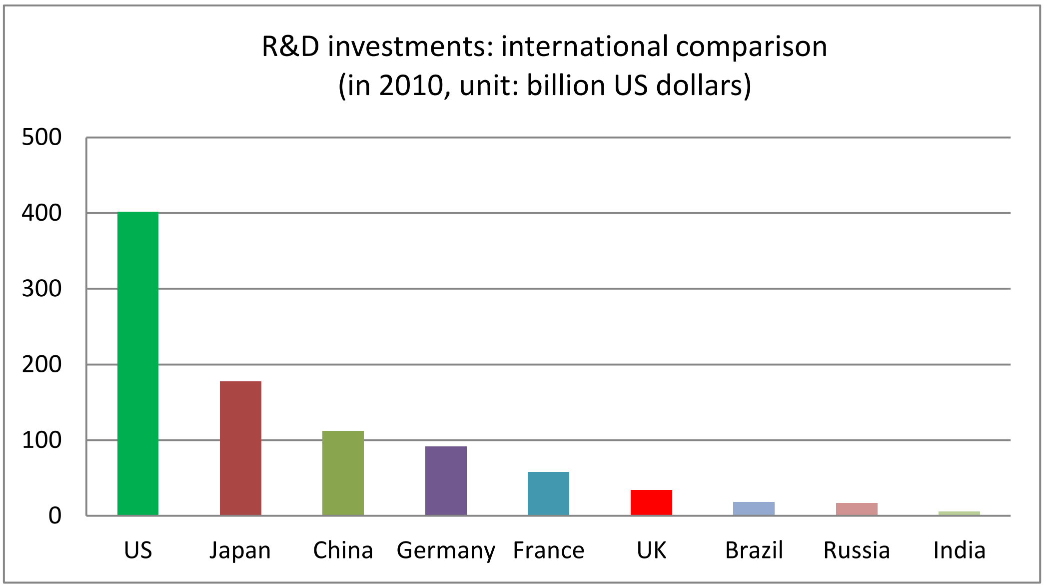

Figure 1: R&D investments: international comparison of Gross domestic expenditure on R&D (GERD). Source: OECD

With the increased investment on R&D, China's science and technology sector has achieved remarkable success. For example, China's internationally granted patents increased five-fold from 3,284 to 16,652 between 1990 and 2011 [15]. In 2011, China's international patents accounted for 9% of the world total, ranking 4th globally. Similarly the papers indexed by Science Citation Index (SCI) and Engineering Index (EI) more than doubled between 1995 (14,771 papers) and 2000 (36,599), and accelerated still further to reach 240,400 papers by 2011. China's scientific publications has reached 8.4% of the world total, ranking second after the US, which accounts for 29% of all published papers globally [15].

In addition to its indigenous efforts, China has also received large amount of foreign aid in science and technology sector via both direct and indirect channels, especially via international trade. As the Chinese economy grew, it increasingly came to rely on exports, rising from 20% in 1999 to 39% in 2006, driven primarily driven by trade in high-tech goods[1], before falling back down to 26% in 2013. Exports of high-tech goods accounted for less than 10% of total exports in 1990, climbing to approximately 20% in 2000 and further to 35% by 2011.

China's high-tech exports are the product of foreign invested enterprises [19], which was especially true during 1990s. For example, the exports of electronics and electrical appliances produced by foreign invested enterprises accounted for more than 80% of the total volume, which reduced to about half in 2000 [20] and further to 30% by 2005. Many foreign enterprises have established research centres in China. According to von Zedtwitz [21] there were 199 foreign R&D facilities in China at the beginning of 2004, from less than 10 in the early 1990s. These numbers indicates that China is on one hand the world

[1] The high-tech goods include commodities of manufacture of medicines, manufacture of aircrafts and spacecrafts, manufacture of electronic equipment and communication equipment, manufacture of computers and office equipments, and manufacture of medical equipments and meters.

most favourable destination for foreign investment [22] and even more attractive place to do R&D [23]. Foreign direct investment flows to China reached $124 billion in 2011, when flows to the services sector surpassed those to manufacturing for the first time [24]. But on the other hand, China's science and technology industry is still heavily dependent on foreign inputs.

To better understand the driving forces in China's recent R&D prosperity, we extracted and refined data from Chinese official statistics to conduct an empirical analysis to assess the policy and economic drivers with distinction between domestic investments and international spillovers.

3. Drivers: economic prerequisites vs. policy implementation

Many scholars have discussed the driving forces of Chinese R&D from different perspectives. Since the 1980s, studies were conducted to qualitatively discuss the structure and organisation of Chinese science and technology sectors [e.g. 25,26, 27,28]. Liu and Lundin [29] presented significant changes in the Chinese science and technology sector were driven by the shift of the Chinese innovation system from a planned economy and assimilation of the imported technology mainly from the former Soviet Union, to a market-oriented and enterprise-led joint innovation system. Along with the significant flows of foreign direct investments (FDI) to China, scholars have evidenced the significant impacts to technology spillovers to China [e.g. 28,30,31,32]. Furthermore, some latest work has been extended to the qualitative discussion on the benefit of R&D

globalisation for China [23] and to model global R&D spillovers to certain economic sectors, such as pharmaceutical and electronic sectors [33] and energy sectors [34].

China's reforms in the S&T sector essentially consisted of two elements: economic reform and policy reform. Generally speaking, the economic reform was the key drivers for Chinese R&D in the 1980s. For example, the linear correlation between the annual growth of Chinese domestic R&D investment and annual GDP growth was 0.86 from 1995 to 2011. In section 3, we will further investigate the specific driving forces to the developments of China's R&D investments and S&T achievements over the past two decades.

On the other hand, import of key equipment and operational knowledge was the main route for China to gain advanced technologies, even in today. The policy reforms established a more direct channel for China to purchase or jointly research and develop technologies from/with foreign partners. In fact, those direct technology imports have rarely been impacted by change of economic conditions. For example, the correlation between technology imports measured in million 2005 US dollars and Chinese total imports was less than 0.1 during the period of 1978 to 2007. At the same time, China's technology imports have been largely driven by geopolitics and international cooperation policies with western countries. In section 4, we illustrate the patterns and trends in China's technology imports from different perspectives.

4. Investment patterns of Chinese domestic R&D

4.1 R&D expenditure by types of research

Prior to the 1980s, China's innovation system had little basic or applied research, and that was primarily focused on the military [29]. China imported technologies from the former Soviet Union, Japan and Germany [28]. Those technologies laid the foundation for the Chinese chemical, automobile, steel, textile and many other industries [29].

Thirty years after its economic reforms, China has demonstrated that it has capacity to be a leader in research and development for certain technologies such as digital communication and aeronautics. But in most sectors, Chinese R&D activities still focus on refining the technologies or processes into immediately usable products or services – China spends 83.4% of its total R&D expenditures in technology deployment. By contrast, only 4.7% was spent on basic research and 11.8% on applied research. Investment on basic and applied research is still much higher in most developed countries, e.g., 13.3% and 22.4% respectively in Japan, 18.7% and 21.3% in the US, and 24.1% and 36.2% in France. Still, in spite of a GDP per capita that is still much lower than in the west, China's figures are not dissimilar to those of the UK in the early 1980s, which was 6.3% for basic research.

4.2 R&D expenditure by source and sector

Prior to the 1980s, China's plan-based innovation system was linear and hierarchical with clear boundaries and allowed little space for curiosity-driven research [29]. Government funding was the main source of R&D funding. Governmental research institutes played a leading role in R&D, and organised to meet various goals and orientations. For example, the Chinese Academy of Sciences was established in the early of 1950s to take the lead on basic research at the national level together with 39 top research oriented universities, the so-called '985 universities', including Tsinghua University and Peking University. Furthermore, at the national level, a wide range of industrial research institutes were set up to conduct applied research and developmental projects for different specified industrial technologies. Regional governmental research institutes focused on the requirements of regional development. The higher education sector played a complementary role to the research institutes, but without much research activity, focusing instead on applying technologies in specific industry sectors. Enterprises only served as manufacturing and sales units, and did not normally engage in R&D activities, few of even the largest state-owned enterprises had R&D facilities and conducted technology deployment.

Since the 1980s, China's S&T sector has gradually transitioned to an enterprise-centred system [32]. The pattern of Chinese R&D expenditure is now quite similar to that of many western countries such as the US and Japan. Enterprises accounted for 76% of total R&D in China in 2011, compared with 70% in the US and 77% in Japan. The remainder of the funds are from governments (e.g. 15% in China, 12% in the US and 9% in Japan) and foreign and other sources (e.g. 9% in China, 18% in the US and 14% in Japan) [15]. By contrast, if we look into the income sources of Chinese research institutions, the vast majority of funding, 86.2% is from governmental funding bodies, whereas 3.8% and 10% were from firms and foreign and other sources, respectively. The situation for higher education institutions is slightly different – although government is still the dominant funding source for their R&D. As a result of relations with the business sector, 73.9% of R&D budget came from enterprises in 2011, compared to 21% from government and 5% from foreign and other sources.

4.3 R&D investment by region

China is a massive country with great regional disparities. Generally speaking, one would expect more economically developed zones to attract more R&D funds. However prior to the reforms, Chinese R&D strategy was closely linked to geopolitics. During the 1950s, China's R&D facilities were constructed in the Northeast – close to the former Soviet Union, to allow easy assess to Russian technologies. During the 1960s and 1970s, after the Sino-Soviet alliance broke down, China relocated their S&T assets along with the defence and heavy industries to its interior provinces [19]. This inland location was deemed a "Third Front" and thought to be beyond the reach of potential enemies [35]. This strategy resulted in S&T activities being removed from the areas that saw the most dynamic economic growth, i.e. the coastal regions, where production and consumption was increasingly concentrated. After the reforms, along with the economic boom along the coast, China's out-dated production technology and equipment could not cope with the modern production, especially in light industries. The coastal provinces were attracting foreign direct investment primarily from Taiwan and Hong Kong and investing in R&D capacity to gain the latest technology. Taken together, the coastal provinces (including Beijing and Tianjin) accounted for 6.2 billion Yuan or almost half of the total R&D investment in 1990, which increased to 912.6 billion Yuan by 2011. In contrast, the interior was relatively less attractive for R&D investment. Starting with slightly more than half of the total R&D budget in 1990 (6.4 billion Yuan), R&D in the interior dropped to about one-third in 2007 (61.9 billion Yuan) and still further to 28% (250 billion Yuan) in 2011. Over the period 1990 to 2011, the average annual growth rate of R&D investment in the coastal provinces was well over 20%, whereas the interior provinces grew at roughly 13% - 14%.

Furthermore, if we look into the details of R&D expenditure by sector by region, there are significant differences. In 2011, about half of total regional R&D expenditure in Beijing and Tianjin was spent by research institutions (meaning more basic and applied research), which is reflected by the fact that 36% of governmental funding was invested in this region alone. Of course, government funding was not only or even primarily aimed at regional research and development, but rather was used to strengthen national R&D capacity as the research institutions in Beijing and Tianjin conduct research at both national and regional levels. In contrast, R&D investment in most other regions was mainly sponsored by firms. For example, 95% of the R&D budget in other coastal provinces was from local firms and spent on regional enterprises' research activities in 2011 [15] .

4.4 Large and medium-sized enterprises' S&T activities in sectoral details

As noted above, Chinese firms, especially large and medium size enterprises, have played a leading role in research and development since the reforms. In this section, we investigate the pattern of firm-level research and development since the 1990s, for which, absent other measurable indicators, we use expenditure on science and technology activities.

Investments by large and medium sized enterprises on science and technology activities have increased over 40-fold from 1990 to 2011, rising from 9 billion Yuan to 364 billion Yuan, measured in constant 1990 Yuan, as shown in Figure 2. At the start of the period, non-metallic minerals, chemistry and machinery were the leading sectors, and together accounted for more than half of the total science and technology budget in the early 1990s. However, the sectoral distribution has gradually changed in parallel with changes in the Chinese manufacturing structure towards more value-added and export-driven products. Electric and electronic products, metal products and machinery have become the dominant sectors, accounting for 60% of China's exports. In 2011, Chinese firms invested 105 billion in 1990 Yuan on science and technology activities for electric and electronic production sectors. The figure has increased over 100 times compared with about two decades ago. Similar phenomena can be observed in many sectors such as metal processing and production, chemicals and machinery.

One of the main drivers of the dramatic increases was that Chinese firms were seeking to gain advanced foreign technologies in order to produce exports to western standards. Purchasing key equipment and production lines were the main ways to acquire advanced technologies prior to 2000, which accounted for about 85% of total value of technology imports. Increasingly, China has sought to transform itself from an economy built on manufacturing ('made in China') to one focused on service and creativity ('designed in China'). The proportion of technology imports spent purchasing key equipment and production lines fell dramatically to 26% in 2007 and then further to 3% by 2011. In contrast, the proportion of technology licensing and transfer has grown from 13% to 45% during 1991–2011. A similar increase can be observed for technology consultancy and services.

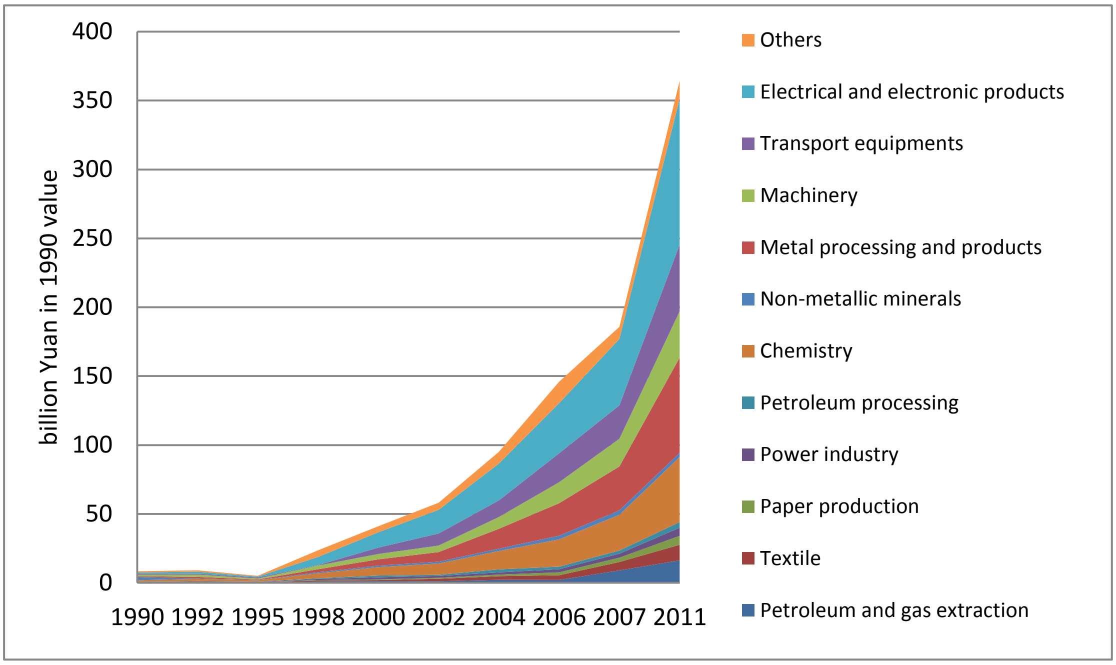

Figure 2: China's Enterprises' S&T expenditures by industry sectors from 1990-2011

4.5 Performance of research institutes in research and development

Governmental research institutes play an important role in China's national innovation system, which conducts basic research, strategic advanced technology research and development and social and cultural research. In 2011, governmental research institutions spent 44 billion in 1990 Yuan on R&D activities, but more than half of that total expenditure was for high-tech sectors such as aviation and aerospace (31%) and electronics and communication research (18%). Such expenditure patterns are similar to those of many western countries. Furthermore, research institutions spent 12% of the total budget in the engineering and basic science sector, and the remaining one third was shared among other sectors, such as earth sciences, agriculture, biology and physics.

It is noteworthy that R&D expenditure by research institutions in environmental sciences and energy technology is the fastest growing research area in recent years. Its R&D spent has doubled in real terms from 280 million in 2007 to 571 million in 2011, measured in 1990 Yuan. China is the world's largest CO_2 emitter [12], which increases the pressure from the international community for China to take responsibilities on climate change mitigation. China has shown great interests in implementing low-carbon technologies: for example, the annual installed capacity for wind power almost doubled every year since 2003 and China has closely working with EU on building CCS (carbon capture and storage) power plants (e.g. the EU-China Near Zero Emission Coal or NZEC project).

R&D activities conducted by Chinese governmental research institutions are largely implemented independently, accounting for 83% of the total value of the projects. Furthermore, 8% projects are collaborated internally with other governmental research institutes. Within the less than 10% of projects that were collaborated, 2% each was with domestic enterprises and higher education institutes, respectively. There are less than 2% of projects that are collaborated internationally, either with foreign enterprises or overseas institutes.

4.6 Current status of Chinese scientific publications

Chinese scholars have seen great increase in publishing papers since the early 2000s. As noted above, China is second to the US in terms of the amount of papers indexed by SCI, EI and ISTP systems, which was only ranked as the 10th in 1999 [36]. Furthermore

China's international journal publications indexed by SCI by 2010 accounted for 4.1% of world total ranking as the world 2^{th} largest after the US. The more engineering research based publications indexed by EI accounted for 11% of world total, top of the world.

Indexed journal publications are dominated by relatively few subject areas. In 2011, Chemistry accounted for 25.4% of China's total indexed publications, followed by Biology (13.4%), physics (12.1%), materials science (7.1%). At the same time, those are also the leading subjects by China in terms of publication record globally. Higher education institutions are the major source of published journal papers, accounting for 83.7% of total indexed publications by the three major indexing systems. Governmental research institutions' publications accounted for 15.1%; and the remainder (less than 1%) was shared by enterprises and medical institutions.

The dramatic increase in scientific publications in recent decades has been driven in a general sense by significant R&D investments [37,38], but the more direct drivers are graduation/promotion related and bonus-driven incentives for journal publications in almost all major Chinese research institutions and universities.

The Chinese higher education sector has produced the largest number of postgraduates and teachers in the world -- 1.6 million and 1.5 million respectively in 2011 [29]. China is also the world leading PhD producer with over 100,000 PhD graduates every year [6]. Since the early 2000s, many universities, in order to enhance their research reputations, require students and academic staff to publish in journal as a pre-condition to receiving their degrees or for promotion [40,41]. For example, Zhejiang provincial Education Ministry in 2005 stated that *"full professorship requires … 8 papers…; associate professorship requires … 5 papers …"* [quoted in 30]. Furthermore, most Chinese universities and research organisations have designed bonus-based incentive schemes to motivate academic publications. For example, Harbin Institute of Technology – one of the leading Chinese engineering universities, implemented an incentive policy in 2003 whereby: *"every SCI indexed publication would be awarded 6,000 Yuan; … [and] every EI indexed publication would be awarded 1,000 Yuan; …every ISTP indexed publication would be awarded 300 Yuan …"* [quoted in 40].

The career-related and bonus-based incentives for publications have largely driven the boom of Chinese academic publications in recent years. However on the other hand, such policies also induced gamesmanship among both researchers and the academic publications. For example, even though researchers will target lower quality journals to facilitate acceptance, there is still not enough capacity to accommodate given the rapidly increasing demand. Many domestic journals will therefore create supplements to accommodate many more papers. Some journals have even produced supplement sections explicitly for postgraduates in order to help them graduate [41]. In exchange, researchers who are willing to publish in those journals have to pay high fees which are labelled as a "printing charge", "review charge" or "express publishing charge" [40]. A survey conducted by East China Normal University showed that 90% of postgraduate students paid at least the printing charge to publish their papers [42]. In fact, 70% of the better domestic journals require the payment of a printing charge (e.g. 100 Yuan per page) before the publishing process [40]. Many scholars have questioned and criticised the impact of such policies on quality of research [43, 44]. The total citation rates can be an indirect indicator to reflect this.

Based on absolute numbers of publications and influence, Chinese research has shown dramatic improvement [36]. According to Essential Science Indicators, Chinese publications in the Web of Science were second to only the United States (3.4 million to 1.3 million) and the number of citations was just below 10 million in 2014, ranking China 4^{th} in the world, just behind the UK and Germany both on 12 million but well behind the US at 55 million. [65] This is an increase from being 7^{th} in the world in 2011, 13^{th} in 2007 and 19^{th} in 2002. Between 1999 and 2008, China's citation share in the global total rose from almost nothing to 4% [45]. In contrast, the United States has been relatively stable, accounting for roughly 30% of global citations [45]. The number of cites per paper remains significantly lower than in any of the other leading countries (7.4 cites per paper, half that of US, Germany, and the UK, the three leading countries, which range from 14.3 to 16.3 cites per paper).

5. China’s international technology spillovers

As part of its early economic reforms, China concluded a bilateral agreement with the US on S&T cooperation in 1979, which remains in effect [19]. Since then, China has established bilateral or multilateral S&T initiatives with most western countries. China and the EU signed an S&T agreement in December 1998 [46], which was renewed in 2004 and renewed again in 2009 for another five year period. This has been supplemented by a 'China-EC Science and Technology Partnership Scheme' in 2009, an 'Administrative Arrangement' with the National Natural Science Foundation of China in 2010 to "launch research projects in specific research areas of common interest" in 2010 and more recent initiatives on innovation in 2012 and 2013 [63]. China's emphasis on rapid S&T development was enunciated by Deng Xiaoping –"*the next century will be the century of high technology*" [quoted in 47 p.160]. The shortcut needed to access high technology is to "*exploit resources available from the international environment* [48]. In particular, Suttmeier, Yao and Tan describe how this path has involved a series of steps including sending large numbers of students and scholars abroad for advanced training; developing a foreign investment regime intended to exploit financial, managerial and technological assets held by foreign firms in China; signing numerous agreements with foreign governments for scientific and technological cooperation; and purchasing vast amounts of foreign technology [48].

Some researchers have studied the data on Chinese overseas students and scholars [49,50]; and many studies have discussed the technology spillovers via foreign direct investment channels [e.g. 23,28,30,31,32]. In this section, we use contracts for imported technology (measured by monetary value) as our key indicator, to illustrate the "purchase of vast amount of foreign technology".

China has gradually become one of the world largest markets for technology imports. Since its economic reforms, the annual volume of technology spillover contracts China has signed increased more than four-fold from $5.7 billion in 1979 to $25 billion in 1991 and further to $53.8 billion in 2011 (all figures given in 2005 US dollars). The following sub-sections describe the driving forces by sector, type of technology and country of origin.

5.1 Imported technology contracts by economic sector

As shown in Figure 3, imported technologies contracts have become common in the manufacturing sector since the early 1990s, and usually accounted for 40% - 60% of the total. In some years, such as 2002, the manufacturing sector accounted for as much as 85% of the total monetary value of technology contracts, which was driven by several important policies i.e. China and the US renewed the Protocol on the Cooperation in the Field of Industrial Technologies and S&T Information [51]; China strengthened its cooperation with UK on e-science [52]; China and France established cooperation in electric vehicles etc [53].

If we further break down the manufacturing sectors, the imports of electronic technologies and advanced production technologies has been the leading sectors, which accounted for 36.4% and 13.8% of total monetary amount of technology contracts in 2007, respectively.

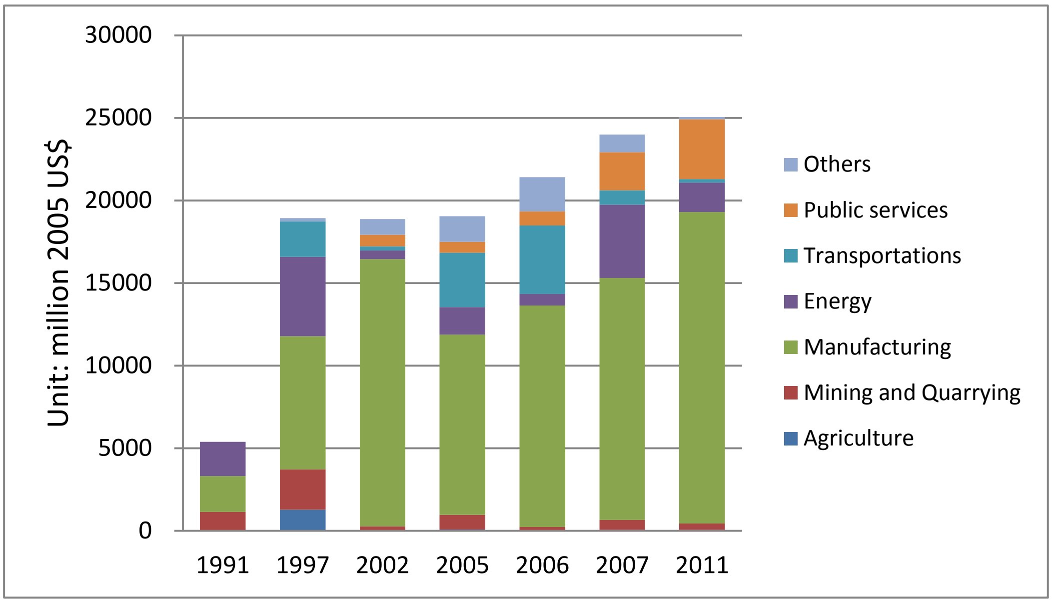

Figure 3: China's imported technology contracts by production sectors

In terms of imported technology contracts, energy is the second largest sector after manufacturing. A former Chinese Minister of Science and Technology, Xu Guanhua, expressed the view that China would strengthen its opening to the outside world while doing so domestically, particularly for environmental and energy technologies [54]. In 1991, China signed $2,073 million (2005 US dollars) in new energy-technology-related contracts, and that figure doubled by 1997. Imported technology was mainly used to increase the efficiency of coal power plants and build nuclear power plants. However since the late 1990s, such imports began to decline reaching its lowest point of $519 million (2005 US dollars) in 2002. In recent years, the figure has rapidly climbed back up and by 2007, China's imports of new energy technologies had grown eight-fold to $4,443 million (2005 US dollars), accounting for about 20% of total China's imported technology. Recent technology imports have been used in major energy projects such as the Three Gorges power project, key nuclear power plants, electricity and natural gas transmission projects from resource-rich western China to the country's power-thirsty eastern part and advanced low-carbon technologies driven projects. For example, China has built over 400 wind farms, with over 20,000 turbines and a total installed capacity of over 60GW by 2011 [55].

More recently, the tide has shifted and virtually all of China's rapidly increasing renewable penetration is produced domestically and China has become the leading exporter of green energy technologies. China has achieved great success in producing photovoltaic (PV) cells, which grew five-fold from 2005-2010 to become the world's largest solar PV cell producer [56]. Since then both production and domestic deployment has increased dramatically. In 2013 alone, China installed 12.1 GW of solar capacity (an increase from 3.2 GW in 2012), almost all of which was produced domestically, which is a one-year record for solar deployment of any country. [66]. Similarly, investment in wind energy led to capacity doubling every year from 2005-2009, so that by 2013, China had deployed more than 10 GW of wind power for five years in a row. [66] But the rapid deployment also meant that there has been overinvestment and some estimate that, in 2012, 30% of wind turbines sat idle because they cannot be absorbed or integrated with the grid [55].

Further, China has increasingly begun to invest in foreign countries as seen in the case of green energy. According to a recent World Resources Institute report, over the past decade, China made over 120 investments in renewables in 33 countries (roughly 2/3 in solar, 1/3 in wind). The cumulative value for 54 of those investments (those WRI was able to document) amounted to nearly US$40 billion, and the cumulative installed capacity added was nearly 6,000 MW [64].

5.2 Imported technology contracts by types of imports

As shown in Figure 4, importing key equipment and production lines was the dominant mode for China to gain advanced technologies during the 1990s, and accounted for about 85% of the total annual technology imports before 1999. This also reflects that Chinese had an established tradition of interest in learning from and imitating foreign technologies [57], to increase productivity and reduce labour intensive production, which were the prioritised tasks for most of Chinese manufacturers at that time. Furthermore, China reconciled to produce cheap-labour costs and resources intensive commodities to drive the economic boom, as the national development strategy was focusing on economy at that time. In recent decade, China started to vary its foreign technologies imports. The imports of key equipment and production lines dropped dramatically between 1997-2002 to less than 25% of total imports, while IPR-related imports rapidly increased. For example, technology licensing and patent transfers together accounted for around 10% of total imports in the 1990s, but increased to 45% by 2011. Such change has been largely driven by China's S&T strategy, especially in recent years; China sets its S&T development as a top priority. The most recent national S&T programme for the period between 2006 and 2020 have emphasised that patents-driven technology imports would plays a key role in S&T development [23], and indicated that rapid increase of advanced technology transfer will be sustained. This has demonstrated China's ambition in leading science and technology sector in the global scale.

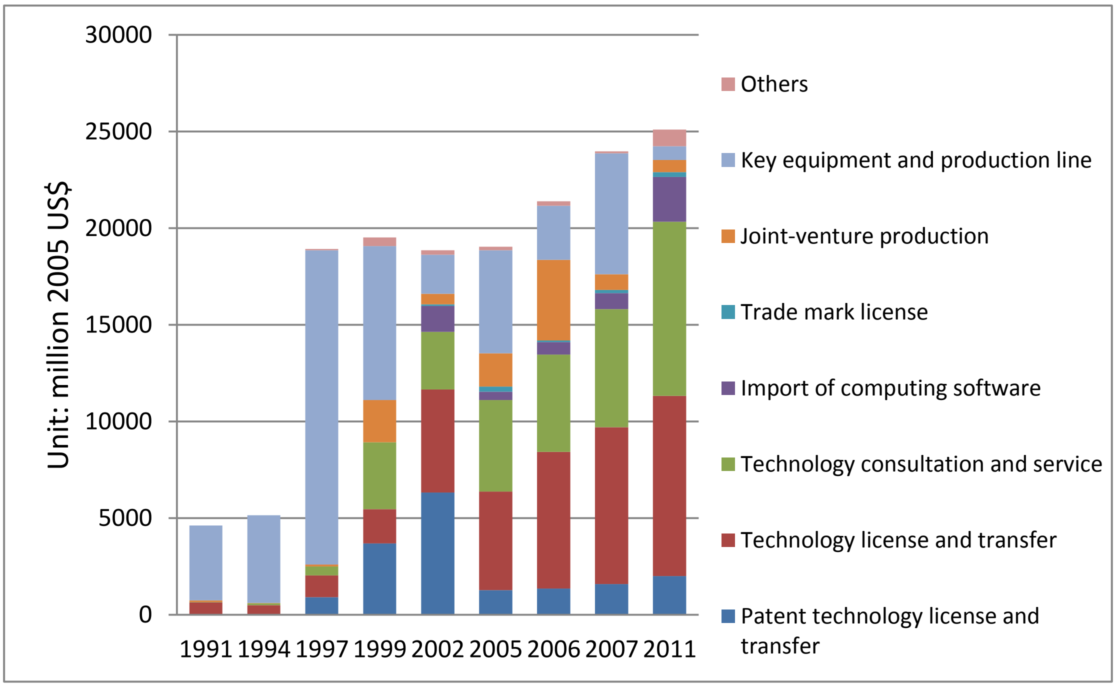

Figure 4: China's imported technology contracts by types of imports

5.3 Imported technology contracts by country of origin

Prior to the reforms, China's technology imports were aimed mainly at strengthening the productivity in heavy industrial sectors. During the 1950s, equipment was imported from the former Soviet Union and other eastern European countries for the metallurgical, electric power generating, machine-building and aviation industries, which were used to equip 156 national principal projects mainly located in Northeast China [19]. With the technology aid from the former Soviet Union, China laid the initial foundation for industrialisation. During the 1960s, after Sino-USSR relations deteriorated, China switched its technology sources to western countries and started to receive technologies from Japan. From 1966 to 1976, largely due to the chaos of the "cultural revolution," technology imports in particular were interrupted.

Since 1978, China recovered its trade and technology imports with some developed countries. In February 1978, China signed a medium term contract with Japan for the import of modern plant as well as building materials and technical know-how [58]; In return China had to export crude oil and raw materials to Japan. Japan remained the largest technology source of technology until almost the end of the 1980s. At the same time, China initiated trading and technology imports from the west. Germany (West Germany prior to 1990s) was the main trading partner in EU and one of the main technological sources for China. In return, China had to export food and raw materials to balance the bilateral trade [58].

Large-scale technology imports have actually accelerated since the 1990s. Annual technology imports contracts decreased from $5.6 billion (2005 US$) in 1979 to $1.7 billion in 1990, before growing rapidly to almost $25 billion by 2011, although there were a few significant drops during the 1990s. Every significant change in technology imports contracts was driven by China’s foreign policy or geopolitics. For example, the big boom in the middle of 1990s, as shown in Figure 5, was driven by the “market in exchange for technology” policy implemented by Chinese industry [49]. Since 1995, many local firms have either formed joint ventures to attract foreign direct investment, or purchased technology directly. This policy guided Chinese S&T strategy and greatly increased the volume of technology imported in the following years [60]. By contrast, the sharp drop of technology import contracts in 2001 was largely driven by a single international incident – the mid-air collision of US and Chinese military aircraft south of Hainan Island in April 2001. The amount of signed technology imports contracts dropped more than half from over $20 billion (in 2005 US$) in 2000 to $10 billion, but climbed back to $18 billion in 2002. The rapid recovery was the product of both the mended diplomatic relationship between US and China and China's successful entry to the World Trade Organization (WTO). Thereafter, WTO-related reforms allowed foreign enterprises to establish wholly foreign-owned subsidiaries in China [19].

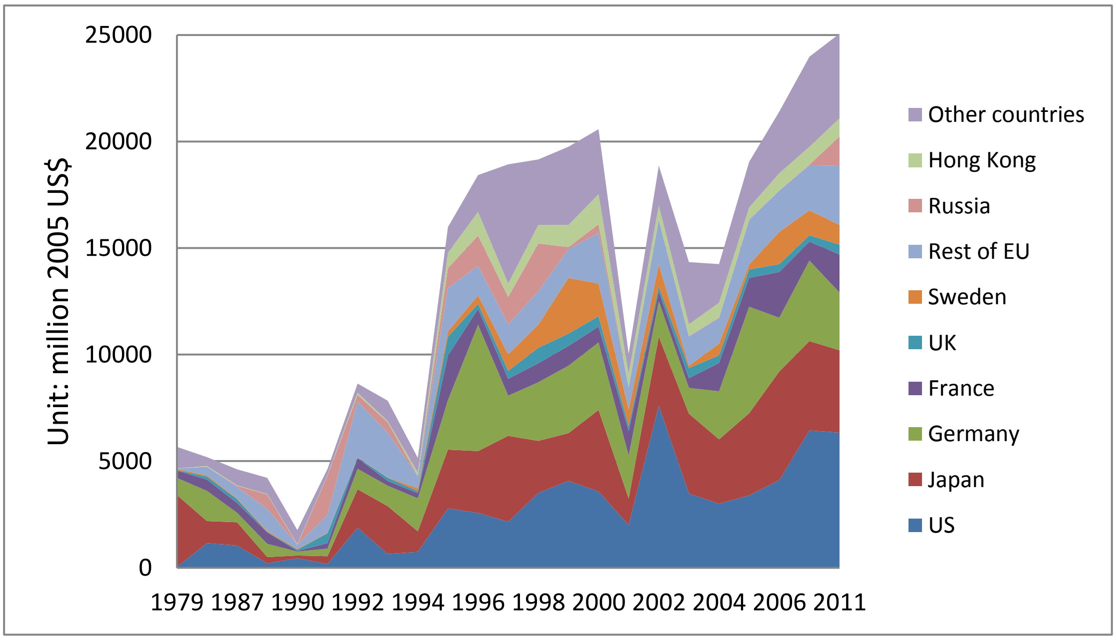

Figure 5: China's imported technology contracts by country of origin.

China has established technology import relationships with about 80 different countries, including all major developed countries. The cumulative amount of technology imports reached over $330 billion (2005 US$) over the course of 1990-2011, drawn from three main sources: US, EU, and Japan. The EU has been the largest source, accounting for about 40% of the total, of which Germany contributed 40% of total EU's technology exports to China, while France, Sweden and the UK combined to account for one-third of Sino-EU technology cooperation. The US was the country that was the largest single source of technology, accounting for 20% of total Chinese technology contract imports during 1990-2011, followed by Japan (18%) and Germany (15%).

China's technology imports are mainly located in those more economically developed regions: the coastal provinces (including Beijing and Tianjin) received almost 75% of technology imports in 2011, and the situation has been barely changed since the 1990s. The persistence is due to the much better facilities and knowledge-absorbing capacity that the more economic developed regions can provide. Foreign investors and collaborators have generally shown little interest in investing in developing regions, for instance, opening R&D centres in western China, even though China has pushed hard to develop these regions in recent years [61]. It this phenomenon continues, the R&D gap between Chinese regions will grow still further, compounded by weak technology spillovers, and become a barrier to China's ambition to transform itself into to an innovation-based economy.

5.4 China technology exports

Technology imports have given an essential boost to the development of China's core industries and created new priority areas for economic growth and trade. China increasingly plays the role of hub in connecting the global North and South in terms of trade in products as well as technologies. China started exporting its technology in the early 1980s, but the principal growth in its technology exports was achieved only in the 1990s. During 1991-1998, China engaged in technology trade with over 100 countries, with cumulative contractual volume amounting to $32 billion (2005 US$). The major recipients of Chinese technology were developing countries in South Asia, South America, Europe and Africa. In 1998, China's technology exports consisted of software (5%), complete sets of equipment (65%), high-tech products (20%) and technical services (10%). The machinery and electronics sector and energy sector constituted the majority of technology exports during the 1990s, accounting for 38% and 15% of the total respectively.

Since 2000, China has stopped publishing official data on its technology exports, but evidence has shown that China remains very active in exporting technologies. According to OECD statistics, in 2004 China overtook the U.S. to become the world's largest exporter of information and communications technology goods [62]. Since 2008, Huawei Technologies has been ranked among the top five global telecommunication equipment providers. Huawei owns over 600 trademarks worldwide and its annual exports (equipment and technical services) has reached over $20 billion (2005 US$) to rank first among Chinese private owned companies. Furthermore, China has expanded its technology exports to developed countries for even the most advanced technologies. In April 2009, China Huaneng Group, the largest power company in China, which specialises in clean coal technologies, reached agreement with US firm Future Fuels LLC on exporting two-stage pulverized coal pressure gasification technology, which would be applied to a 150-megawatt IGCC power plant to be built by Future Fuels in Pennsylvania.

6. Conclusions

China’s massive growth in investment into its science and technology industry and enhanced technology trade has paved the way for China to be a global scientific powerhouse. On one hand, China’s rapid increase of domestic investments in R&D has been largely driven by the almost double digit annual economic growth since its reform were initiated at the end of the 1970s, which has yielded even faster rates of R&D growth. However, *R&D in China is more ‘D’* (development) than *‘R’* (research) [19], comparing with many leading western countries. Enterprises provide large amount of fund to mainly engaged in experimental developments. Funding has been largely spent in ‘high-tech’ sectors for export production, including electronics, machinery, and chemical products and so on in order to comply with western standards. The energy sector has been a particular focus and China has recently become the leading investor in clean energy. The government has acted as the major driver encouraging institutions and universities to conduct basic and applied research. Chinese scholars have made great strides in terms of academic publications over the past decade, which had made China to become the second world largest source, after the US, in academic journal publications. Such success has been largely driven by the promotion/bonus related incentives implemented widely across in many national and local universities. China still lags in terms of academic impact though, with the number of cites per paper only half that of its major competitors.

On the other hand, China regards imports as an effective way of gaining advanced technologies. Technology imports have been tied to national development strategies and international geopolitics. Manufacturing and energy technologies are the main targets and EU, US and Japan have been the main sources for those technologies. China's technology importing strategy has shifted from importing 'key production lines' during 1990s to licences and patent-driven imports in recent decades. At the same time, the latest evidence shows that China has taken the advantage of global manufacturing centre to acts as a global technology trade terminal to exchange technologies between countries.

Acknowledgements

This study was supported by the European Commission FP6 TOCSIN project, AXA Fellowship, Chinese Academy of Sciences (71250110083). This work was conducted while Zhu Liu was a joint Giorgio Ruffolo fellow in the Sustainability Science Program in the Mossavar-Rahmani Center for Business and Government and Energy Technology Innovation Policy Fellow at the Belfer Center for Science and International Affairs, both at the Harvard University Kennedy School of Government. Zhu Liu acknowledges the support of Italy's Ministry for Environment, Land and Sea.

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