The Chinese Research and Development System: A Measure of its Specialisation and its Evolution in an International Context

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Resumen: Al analizar la evolución de la inversión en I+D y la producción de resultados como publicaciones científicas internacionales en las últimas dos décadas, el principal hallazgo es el surgimiento de China. Nuestro objetivo es lograr una mejor comprensión del grado de especialización del sistema científico de chino mediante el análisis de la evolución de la fabricación de alta tecnología, la producción de patentes internacionales, la inversión en investigación básica y la producción de documentos de investigación y su distribución en áreas de conocimiento.

Abstract: When analysing the evolution of R&D investment and the production of outputs such as international scientific publishing in the last two decades, the main finding is the emergence of China. We aim to a achieve a better understanding of the degree of specialization of China's R&D system by analysing the evolution of high technology manufacturing, the production of international patents, the investment in basic research and the production of research papers and their distribution in knowledge areas.

Palabras clave: China, I+D, innovación política científica y tecnológica, bibliometría

Keywords: China, R&D, innovation, science and technology policy, bibliometrics

Introduction and Objectives

In 1949, at the time the People's Republic of China was funded, there were only 207 higher education institutions in the country that hosted 117,000 students –less than 0.2% of the total population. In this scenario, the first Five Year Plan started in 1953 with a strong emphasis in heavy industry. Following USSR's guidelines, 42.5% of all investment went to industry, and 85% of it was devoted to the development of new heavy industries Wang (1993). Mao used the Soviet model as a reference for higher education too, and the approaching of separating teaching from research was adopted. Research institutes were isolated from universities and enterprises, and universities focused on teaching only (Wang and Zhou, 2011).

In 1956, the first Scientific Long-Term Plan (1956-1967) was established on the same grounds. The plan aimed to concentrate resources on priority research fields, and most of these fields were linked to heavy industry and defence. A number of researchers, such as Chen (1990) Riskin (1987) Volti (1982a) Volti (1982b) Volti (1982c), consider that this emphasis on research for the heavy industry did remain unchanged for the following two decades, despite the changes in the science policy caused by the political turmoil of the 1960s and 1970s.

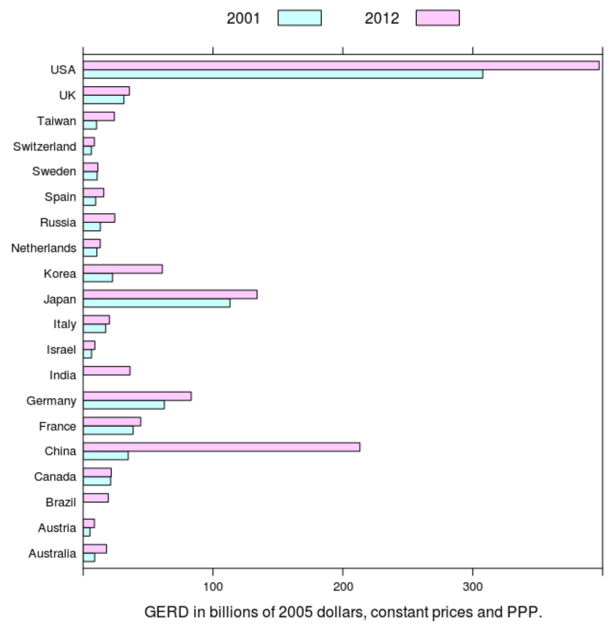


Illustration 1: Evolution of the world's investment in

In 1978, the Chinese government started to add research as part of the universities' mission and to encourage a certain degree of coordination between these and research centres, even when the Government itself retained its role as the central node of the scientific and technological system. The new National Plan for the Development of Science and Technology (1978-1985) was still strongly focused on applied research and heavy industry, but it paved the way for new research fields, such as particle physics and genetics (Wang, 1993). The Sixth and Seventh Five-Year Plans (1981-1985 and 1986-1990 respectively), while still oriented towards short-term economic development instead of generation of knowledge, started a trend where the share of light industry projects increased over the years.

In the last two decades, China has increased the share of its Gross Domestic Product (GDP) devoted to research and development, this is, its research intensity. As shown in figure 1, China's Research & Development (R&D) expenditure as a share of the world total has been growing much more rapidly than these of the United States, Canada, Korea, Japan or any considered European country. This growth is even more impressive given that China's has simultaneously grown by rates over 7% per year on that period, as shown in figure 2.

The current figure for China's research intensity is slightly over 2%, which is still below Korea, Japan, Germany, United States, and France, but already above the United Kingdom, Canada and Spain. Should China maintain this rate of growth, it could reach the main European countries by 2020, and approach the current research intensity of Korea in ten years. Given the increasing significance of the Chinese R&D system it is of the utmost importance to acquire an insight into how China is developing its science and innovation to meet international standards.

However, in order to depict China’s research profile, we need to consider not only its investment in R&D, but also to produce a measurement of its results. We will take into account the evolution of high technology manufacturing, the production of international patents, the investment in basic research and the production of research papers, whose distribution in knowledge areas can lead to a better understanding of the degree of specialization of China’s R&D system.

An increasing R&D expenditure with an emphasis on applied research

While China is a 1.4-billion strong economy experiencing a sustained growth of its annual increase in R&D expenditure, as shown in figure 1. However, China’s research intensity per capita is still low compared to the world’s main scientific powers. According to the International Monetary Fund (IMF), China’s per capita GDP in purchasing power parity terms is slightly above USD 19,000 (as of October 2018), which is close to the world’s average, and its research intensity per capita is only around 18%-21% of these of the top expending (per capita) scientific powers, i.e. the United States, Germany, Korea and Japan (plotted in the upper area of figure 3). The ISO-3166 alpha-3 standard three-letter codes are used here to identify countries.

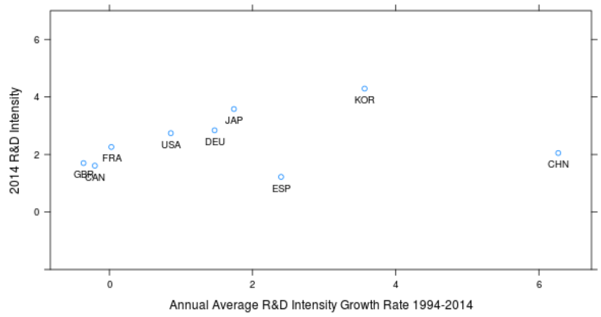


Illustration 2: Research intensity in 2014 (as percentage of nominal GDP) and annual average growth rate of

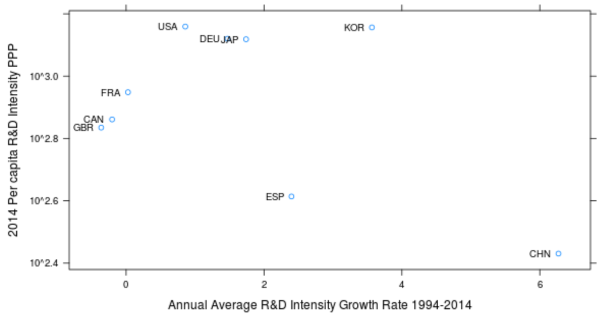
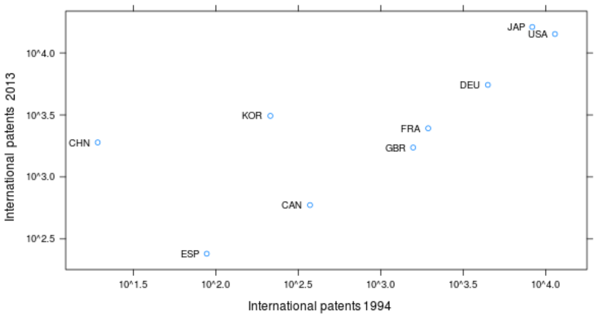


Illustration 3: Per capita research intensity in 2014 (USD) and annual average growth rate of research

The growth of China’s research intensity has boosted its results. Starting in the 1990s, China has successfully improved its position in the international scientific arena and its share of the world’s scientific output –China appears to be transforming into a major player in the world’s scientific arena. A growing investment in R&D (China has already outranked Japan and it has become the second largest performer) and a strong role of a Government-backed industry has reshaped China’s economy, currently focused on value added, high technology outputs instead on just the heavy industry as it did before.

Knowledge- and Technology-Intensive (KTI) manufacturing (such as aircraft and spacecraft; electronics) and services (such as communication; financial), which require high standards and advanced skills, accounted for 27% of the world’s GDP, and this share is on the rise, especially in industrialised economies, where the KTI share grew from 29% to 32% between 1997 and 2012, mostly due to increases in commercial and public (education and health) Knowledge-Intensive (KI) services.

Particularly, the developing world is increasing rapidly its share of KTI production, partly due to China’s successful industrialisation and diversification. Between 2003 and 2012, China high technology manufacturing increased fivefold and its share of global production grew from 8% to 24%, according to the U.S. National Science Board (2014). This is a complete shift of paradigm in the situation of the Chinese industry, as most of the research output was rarely transferred to the industry before the reforms. Simon (1984) and Suttmeier (1986) estimate in less than 10% the amount of all applicable research results when the economic reforms started. This scenario has dramatically changed in the last years. Apart from KTI production, figure 4 shows how China has increased its output in terms of international (triadic) patents from 1994 to 2013, which confirms that technology transfer has improved. While China has increased the number of patents in two decades, has surpassed Spain, Canada, and recently the United Kingdom, and it is approaching some other industrial economies, it is still lagging behind the world's leaders in this field, i.e. Japan and the United States.



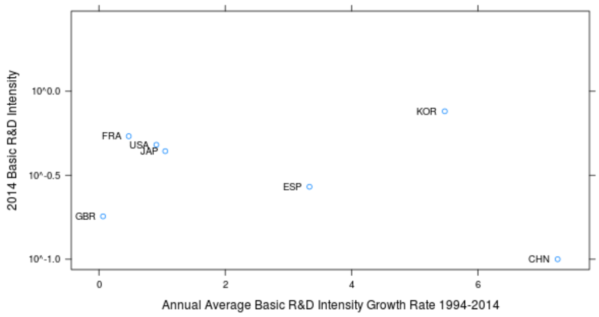


Illustration 5: Basic research intensity in 2014 (as percentage of nominal GDP) and annual average growth

However, despite China's increased production of international patents and the higher value added of China's industrial production, the emphasis on applied research still remains, and China is currently investing more in development and applied research than other industrialized nations, whose effort in basic research is stronger. Investment in basic research accounts for just 0.1% of its Gross Expenditure on Research and Development (GERD). China's basic-research spending has historically been extremely low –about 4.8% of all research expenditure in 2012 and 2013 compared with 10 to 25% in developed nations. However, this trend is starting to be reversed with an increased appropriation for basic research (Qiu, 2014).

Figure 5 shows how while the growth in China's basic research intensity is above any other considered country, its rate is the lowest of all: China (0.1%), United Kingdom (0.18%), Spain (0.27%), Japan (0.44%), United States (0.48%), France (0.54%) and Korea (0.76%). Data confirms that China's investment in basic research is still very limited. Also, it has been shown that China is currently devoted to science and technology applied programmes, i.e. those linked to economic growth, technological development and national defence, at the expenses of social science and humanities. Regarding the outputs of these endeavours, Chinese researchers have dramatically increased their share of the world's scientific publications. Analysing the nature of these publications can lead to a better understanding of the outputs of China's science and technology system, and to evaluate to which extent these reflect the emphasis on applied research of China's current science policy.

A Measure of the Specialisation and Evolution of China's R&D System

The measure of the specialisation of evolution of the Chinese science and technology system can be achieved by building on previously developed research and focusing on one of its main characteristics: how the research effort produces outputs in different areas of knowledge. Analysing the fields in which China's researchers have major activity will allow us to develop a deeper insight of the profile of China's science and technology system, and to have a better knowledge of whether these outputs are contained in those areas that belong to industrial production or not.

In this case, research publications in a set of international journals, and particularly those in the Scopus database because of its coverage, will be used as a bibliometric indicators. This bibliometric variable was succesfully identified by Vinkler (1988), Rinia Rinia et al. (1998), He, Zhang, and Teng (2005) and Tsay (2008) as a reliable measure of scientific production.

In order to better understand the profile of China's research and development system in an internationally comparable way, the research outputs of other eight countries will be analysed in the present paper: the USA as the world's leading scientific power, four major European nations (France, Germany, Spain and the United Kingdom), Japan as leading East Asian scientific power and South Korea as emerging power in the same area. USA, France, Germany and the United Kingdom are considered to be the best performing countries in the West, while both Canada and Spain are of medium strength. Japan and South Korea are considered to be among the scientific leaders in Asia as noted by authors such as Leydesdorff and Zhou (2005), Zhou and Leydesdorff (2006), Shelton, Foland, and Gorelskyy (2007), and Glaenzel (2008). We will then consider whether China's profile is trending towards one or more of these nations or if it is a kind of its own.

It has been already evidenced the fact that China is heavily investing in applied science. In addition to this, in order to provide further evidence of China's emphasis in science and technology applied research, and particularly those linked to economic growth, technological development and national defence, at the expenses of social science and humanities, the study of the research output will be split into coherent disciplines, to gain a further insight into the nature of China's emergence as scientific power.

It has been shown that Asian countries are starting to contest the West's lead in scientific output (Von Bubnoff, 2005). As a country's research impact in a given field is related to its innovative capacity (Lim, 2004; Zitt and Bassecoulard, 2008), this approach allow us to consider China's. We aim also to evaluate to which extent China's strategy, previously introduced and summarized as making emphasis on applied knowledge as the main engine of the national economy and a guarantee of sustained economic growth, can be related to its scientific production in terms of research papers published in international, peer-reviewed journals, along the last decades, and the distribution of this production among different represented disciplines and areas of knowledge.

Data shows how the United States leads the world's production of scientific papers, with an output of nearly one fourth of the global output. Other major powers are the main European nations, together with East Asian countries such as Japan and Korea. China appears to be the most important emerging scientific power currently and it competes for the top position as the nation with the largest output.

It is worth noting that the concentration of scientific results has not changed much over a decade, except for the notable exception of China. The main powers in the world scientific arena (USA, Japan, and the main European nations) have maintained their position, but Korea and particularly China show a major increase as show in Figures 6 and 7.

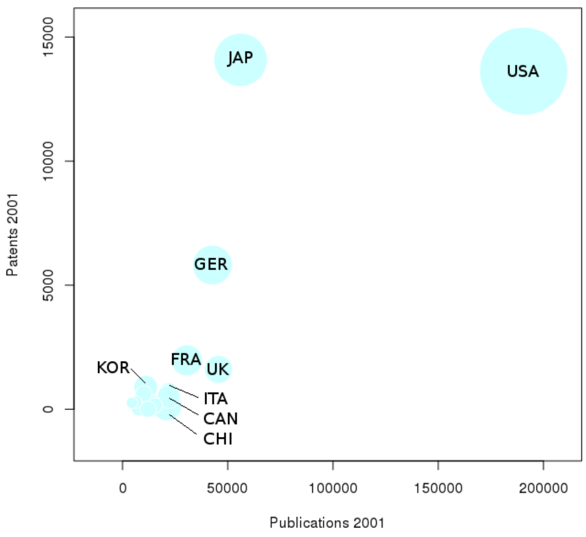


Illustration 6: Worldwide publications and patents in 2001.

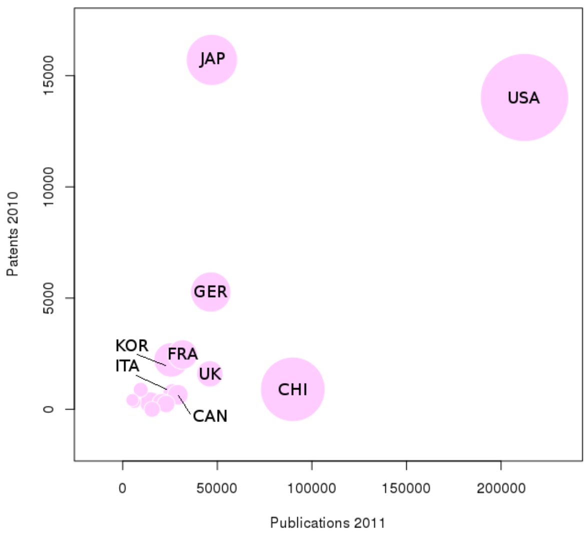


Illustration 7: Worldwide publications and patents in

China, which was only responsible for slightly above 3% of the world's publications in 2001, and climbed up to almost 11% only ten years after that (Royal Society, 2011), is currently the only country approaching the leading position of the USA, with South Korea also increasing its role and major players such as Germany, the United Kingdom, France and Japan losing ground. So a global shift from a trans-Atlantic centre of scientific excellence to an East Asian emerging pole appears to be taking place in the last ten to fifteen years, even when Japan has slightly reduced its presence in international journals.

In order to perform a detailed analysis of the profile of Chinese research output in a way it is comparable to other scientific powers, a classification has been established based in eight general categories that include all fields of science, including life sciences, physical sciences, health sciences, social sciences and humanities. This classification does not aspire to be universal but to offer a coherent approach that can be used to perform a diachronic study of the evolution of the Chinese system in an international context –a common framework is therefore needed.

The purpose of such classification is to divide any further research and analysis in eight different analyses, so when an comparison among different countries is developed, it will be split into these categories. Such exercise will allow us to better understand the profile of Chinese science according to the distribution of its research output in these categories and to better compare its to these of other major scientific powers worldwide.

The eight general categories are established as follows:

1. Arts and humanities.
2. Biological sciences.
3. Engineering.
4. Environmental science.

5. Mathematics.
6. Medicine and health sciences.
7. Physical sciences.
8. Social sciences.

When measuring the scientific output of different countries in terms of articles published in international journals, we have considered any research paper which has been authored or co-authored by at least one scientist based in each of those countries, as the objective is to identify to which extent the research community based in a given country is taking part of the world's research output.

Therefore, the approach to be followed consists in the analysis, year by year, of those articles having at least one Chinese co-author in the last two decades. This will allow us to obtain a grasp of the increase of China's scientific production in terms of research papers. Because of the fact of co-authorship, this will not provide a figure to be used as an absolute indicator, but it will provide a quantitative measure of research output and its evolution, as the same search criteria have been applied for every single year, not only in the case of China but also for every single country studied.

Bibliometric methods such as the publication of research papers in international journals have been widely used to measure scientific performance of countries, and recently the volume of data able to be processed in such analyses has escalated so a more complete profile can be built (Schubert, Glaenzel, and Braun, 1989; Pouris, 1989; Moed et al.,1985). The value of the present approach lays in the fact that the analysis will be conducted along three different axes:

1. A time axis for the period from 1994 to 2014.
2. A specialization axis, as the results will be split in eight different areas of the human knowledge, i.e. Humanities, Social Sciences, Environmental Sciences, Biological Sciences, Health Sciences, Mathematics, Physical Sciences and Engineering.
3. A geographical axis, so the evolution of China as an emerging scientific power can be compared to those of other established East Asian nations, such as Korea and Japan, and also some of the main scientific powers both in North America (United States and Canada) and in Western Europe (Germany, United Kingdom, France and Spain).

Figure 8 shows the diachronic evolution (yearly form 1994 to 2014) of the share of scientific papers registered in the Scopus database with at least one coauthor of each of the following countries: Canada (CAN), China (CHN), Germany (DEU), Spain (ESP), France (FRA), United Kingdom (GBR), Japan (JAP) Korea (KOR) and United States (USA), for each of the eight knowledge areas: Humanities, Social Sciences, Environmental Sciences, Biological Sciences, Health Sciences, Mathematics, Physical Sciences and Engineering.

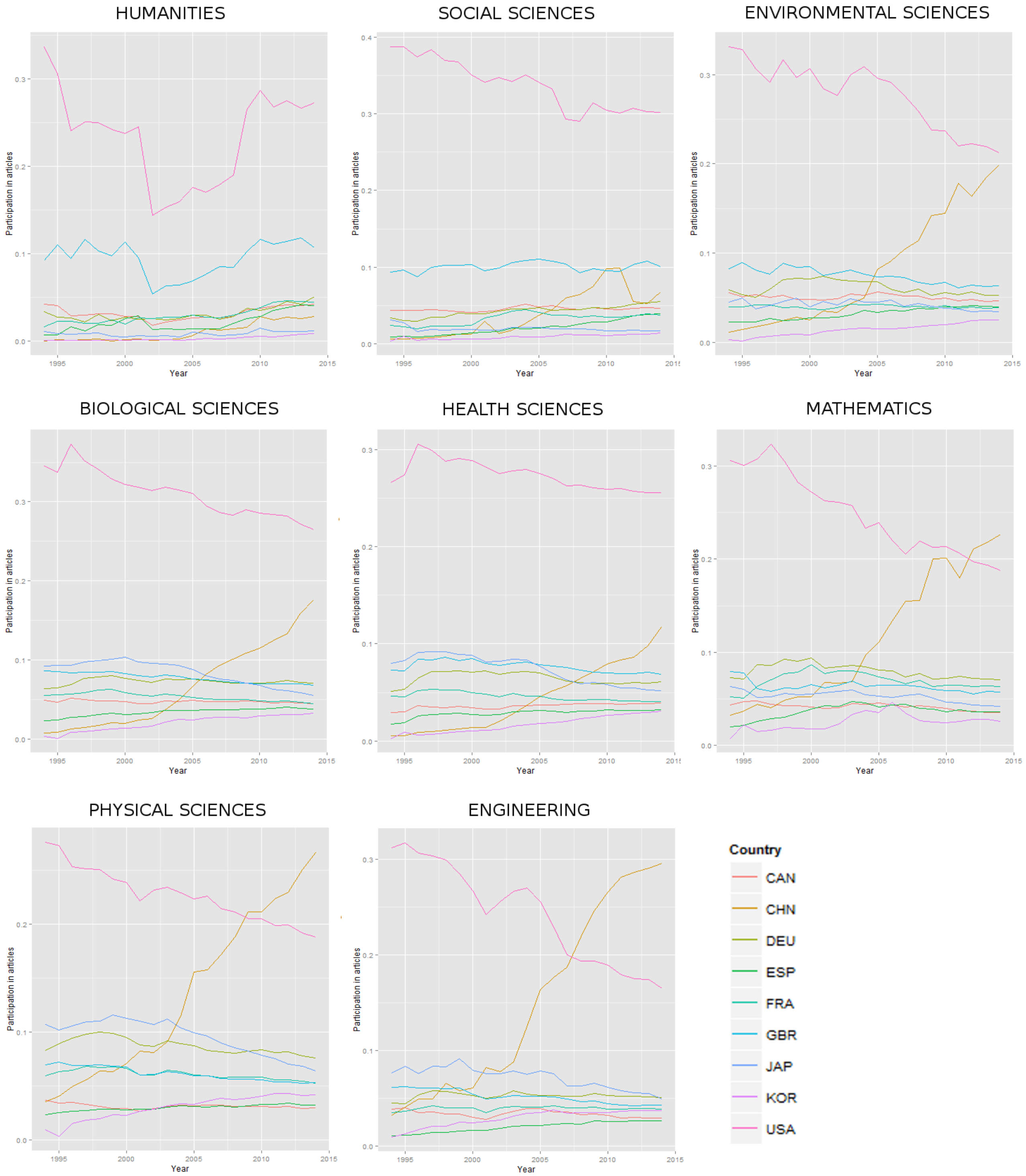


Illustration 8: Evolution of the publication of scientific papers by country.

Conclusions

When analysing the evolution of R&D investment and the production of outputs such as international scientific publishing in the last two decades, the main finding is the emergence of China, which is strongly focused on applied research. This approach is aligned with China's growing production of Knowledge- and Technology-Intensive (KTI) manufacturing and services and a successful technology transfer, which has been measured by considering international (triadic) patents granted to Chinese inventors.

If we focus on research outputs such as academic publications and we take into account a classification of research fields, we obtain a view of the presence of China-based researchers and the level to which they are engaged in research up to international standards. Therefore, regarding the emergence of Chinese authors, three different cases can be singled out:

1. Areas where the research output of China in terms of presence of Chinese authors in scientific papers has only slightly increased over the course of the last two decades, and being its production far below that of the USA or even other major scientific powers. This is the case of the Humanities and the Social Sciences.

2. Areas where the research output of China in terms of presence of Chinese authors in scientific papers has significantly increased in the last two decades and where the last decade has witnessed what it is close to an exponential growth. This is the case of Biological Sciences and Health Sciences.

3. Areas where the research output of China in terms of presence of Chinese authors in scientific papers has already surpassed that of the USA or is about to do so. This is the case of Environmental Sciences, Mathematics, and particularly Physical Sciences and Engineering; the latter was forecasted by McGregor (2010) and others.

It is important to bear in mind that research databases such as the one used here are not exhaustive. In addition to that, some disciplines might be underfunded in China and authors such as Moed Moed (2005), Van Raan Van Raan (2005) and others CHERPA (2010) have demonstrated that medicine and sciences are much better represented in the number of scientific papers published in international journals, than other areas such as engineering, some of the social sciences and especially the humanities, as those indicators primarily cover publications, but not books and other media productions.

Therefore, the results shown in the previous lines cannot be understood as a comprehensive picture of all scientific production available worldwide, but as a useful tool for a diachronic analysis that uses common variables for every country involved, and thus can be helpful to depict the particular characteristics of China's emergence as a scientific power over the last two decades. The results shown in Figure 8 suggest that Chinese authors might be favouring areas such as Mathematics, Physical Sciences and Engineering, i.e. the presence of co-authors based in China might be proportionally higher in these areas of knowledge than in other disciplines.

We have obtained a view of the presence of China-based researchers and the level to which they are engaged in research up to international standards. This is particularly useful when combined with a detailed analysis of the different disciplines to which these papers are related, so the evolution of the knowledge areas concentrating the higher share of the Chinese production can be studied over the years. We might expect a more balanced research mix, similar to those of established scientific powers. This evolution is similar to other emerging Asian economies such as South Korea, which had an earlier start in terms of the development of its science and technology system.

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