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Drivers of China's Convergence to Innovation Leaders

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Abstract

The article focuses on the innovation divide in the world economy, in which some countries are technological leaders whereas the others are technological followers; however, a continuous innovation convergence has been taking place over the last decades. The aim of the paper is to measure the dynamics of the innovation gap between China and both the USA and the EU, and to identify key factors of China's success in bridging the gap with the world's innovation leaders. The analysis indicates the convergence in innovation performance between the analyzed economies, especially when it comes to innovation capability. Key factors contributing to this process are identified and analyzed, in particular: China's science, technology and innovation policy, increased R&D expenditures, human capital development, and the development of clusters and highly specialized industries.

Keywords: *Innovation divide, technology transfer, research and development, science, technology and innovation policy, innovation efficiency, China*

1. Introduction

The article focuses on the innovation gap between China and global innovation leaders, i.e., the USA and the European Union. Recent studies on China's comparative innovation and technological advance have revealed the remarkable technology development of China over the last decade (Kaufmann, 2021; OECD, 2008; Veugelers, 2016). In particular, China is making big progress towards Industry 4.0 as there is a large scope for catch-up automation, with the associated impact on productivity and thus the competitiveness of Chinese enterprises (Butollo, 2021). Lindtner examined the "displacement of technological promise" from the United States to China, demonstrating how China, which was long viewed as a country not capable of innovating, has recently come to be perceived as a prototype nation, a "place to prototype alternatives to existing models of modern technological progress" (Lindtner, 2020: 6). The assessment of China's technological catching up based on patent counts as well as patent quality shows that the country has been converging to technological frontier countries such as Germany or South Korea, with the growing likelihood of surpassing them by 2025 (Jiang et al., 2020). Dynamic processes of increasing the innovative potential of China provide a solid base for further convergence and diminishing the innovation gap between this country and more developed economies, such as the European Union (Kowalski, 2020). Some studies however, proved that huge and growing resources for science and technology mobilized in China resulted in a growing R&D output (such as patents and scientific publications) but have not yet been translated into adequate improvements in innovation performance (Schmid and Wang, 2017).

There is no doubt that the process of China's convergence towards the innovation leaders has already been initiated with the start of reforms and openness at the end of the 1970s, as Chinese leaders understood that knowledge and technology are a basis for sustainable economic development. After 40 years of unprecedented speed in economic growth driven by cheap labour, inward foreign direct investment (FDI) and exports, China emerges as a challenger for established global innovation leaders. China has been consistently increasing expenditures on R&D from 0.57% of GDP in 1995, 1.32% in 2005 to 2.4% in 2020, which is a level similar to that in developed countries. Impressive progress in innovation has been reflected in the latest achievements such as the world's fastest supercomputer Sunway Taihu Light, the world's first aerial passenger drone, the Ehang 184, and jetliner Comac C919 (Prud'homme and Von Zedtwitz, 2018). China's strong push for building innovative capabilities results from the search for new engines of economic growth as wage increases, youth unemployment rises, and working age population shrinks. The ambition of Beijing is to leapfrog and take the lead in emerging industries such as artificial intelligence (AI), fintech, 5G, electric cars, etc., as well as to become the global leader in innovation by 2050. Restructuring of the Chinese economy with shifting focus to knowledge and innovation, together with globalization and China's participation in global value chains resulted in re-positioning of China on the world innovation map. However, the COVID-19 pandemic has caused the weakening of the links within global value chains or even breaking them, with a growing tendency to reshoring and nearshoring (UNCTAD, 2021). This may impact the pace of China's innovation convergence with the EU and the USA. Therefore, the aim of the paper is to measure the dynamics of the innovation gap between China and both the USA and the EU, and to identify key factors of China's success in bridging the innovation gap with the world's innovation leaders.

In particular, the role of China's science, technology, and innovation (STI) policies is investigated, and their impact on catching up with innovation leaders in the pre- and post-pandemic period.

The paper is structured as follows. The next section develops a conceptual framework for innovation divide analyses, which is based on relevant literature, and introduces methodology and data sources. It is followed by the assessment of the innovation divide between China and selected peers. Then main findings of this research are discussed with the focus on factors affecting China's innovation performance that have contributed to the reduction of the innovation divide.

2. Materials and Methods

The theoretical background for this paper is formed by different studies on the technological gap in the world economy (Krugman, 1979; Posner, 1961) and recently in the Central European countries (Jian et al., 2015). The United Nations defined the technology gap as "the divergence between those who have access to technology and use it effectively, and those who do not" (UNCTAD, 2006, p. 3). The innovation gap is a broad concept, although it is related to technological advance. Sachs (2003) explored the global divide between technological innovators and non-innovators and concluded that three key features of innovation processes could explain science and technology gaps: (1) the interplay of public and private sectors in innovation systems, (2) economies of scale, and (3) ecological specificity. As Sachs observed, innovation is partly market driven, but it also requires the government's involvement in providing some inputs and being the end user of innovative solutions. Therefore, the technological stagnation that leads to the innovation divide of poorer countries is a result of the limited scientific capability of the private sector and the lack of purchasing power of the government sector. Furthermore, the production function of new ideas due to the economies of agglomeration can bring better results in already scientifically developed areas which attract talents from all over the world, causing a flow of scientist to the most attractive locations. The brain drain problem coupled with the fact that many technologies are ecology specific and therefore those fit for one ecological setting may be of little or no relevance in other ecological settings, limits the technology transfer to countries technologically lagging behind and slows down the catching up process. Overcoming these difficulties and successfully advancing in innovation requires at the beginning an intensive knowledge transfer from the leaders supported by "a strategic industrial policy aimed at achieving high levels of technological excellence and innovation capacity" (Sachs, 2003: 138).

2.1. Reducing the Innovation Divide – a Conceptual Framework

A lot of empirical studies examined how countries upgrade their technological pattern as they develop (see for instance, Grossman and Helpman, 1994; Petralia et al., 2017). An interesting framework for the analysis of closing technological gaps has been proposed by Stehrer and Wörz (2003), who distinguished three scenarios of technological catching up. The first scenario called "continuous convergence approach" assumes that speed of closing the technology gap to the leading country is the same across all industries. Another scenario described as "climbing up the ladder" by the less advanced country is the case of closing the gap in low-tech industries first, and this process is followed by gap reduction in more technology-intensive industries. The third scenario is the "jumping-up approach". It assumes that technology can be upgraded first in high-tech industries that are usually fast-growing ones. These scenarios show from industry perspective how the innovation gap can be narrowed but do not explain which factors play a key role in this process.

Adopting a macroeconomic perspective and defining the innovation divide as the divergence between nations in their abilities to create, access, diffuse, and use scientific and technical knowledge implies that at least two sides of innovation processes should be taken into account in the analysis: (1) capabilities necessary to create innovation (ability to innovate), and (2) results of innovation activity (innovative position). Furthermore, an important research challenge is to connect the topic of dynamics and determinants of the innovation gap with the concept of innovation systems, which underlines the role of the organizational and institutional arrangements, such as the public policies (in particular science, technology and innovation policy), scientific units, and innovative enterprises, which are considered the most essential agents within national innovation systems (Lundvall, 1992; Meuer et al., 2015). Similarly, there has been a wide range of research on the convergence process in the world economy, but it usually focuses on income levels, especially GDP per capita. There is a strong need to explore determining factors, which impact convergence/divergence processes in innovativeness between different economies. Especially important is the analysis of the mechanism for closing the innovation gap between countries with developed innovation systems and countries with developing innovation systems, such as China. The innovative capacity concept defined as the ability of countries to create and commercialize new-to-the-world innovations (Furman et al., 2002) offers an interesting framework that combines financial and human resources necessary for innovations and links them to institutions. This framework is grounded in Romer's (1990) endogenous growth model, the national innovation system concept (Lundvall, 1992) and the cluster approach (Porter, 1998). Sources of the innovation divide and ways to catch up in innovation performance are closely related to determinants of innovative capacity at national and regional levels. They can be grouped into three broad categories: (1) common innovation infrastructure, (2) cluster-specific innovation environment, and (3) the quality of mechanisms that links these two areas. Each of these three groups of factors can be measured by a set of indicators (Furman et al., 2002). They can be used as innovation gap proxies in measuring the innovation gap between different countries. Common innovation infrastructure covers research and technological aspects of innovation and consists of components characterizing human and financial resources available in the R&D sector, higher education investment and institutional setup of the research sector in a country, including intellectual property protection, openness to international trade and FDI, R&D tax policies, innovation policy instruments. The second group of innovative capacity determinants, i.e. "cluster-specific innovation environment" refers to Porter's (1998) concept of industrial clusters. Many studies emphasize the role of geographical proximity as a key factor in the innovation process (Balland et al., 2015). Clusters are now recognized as an important element of innovation systems, as they group together business and scientific units, facilitating knowledge flows, technology transfer, learning processes, and diffusion of innovation (Kowalski, 2016). Cluster structures are characterized by cooperation and geographical and sectoral concentration, which is crucial for knowledge spillovers and can strengthen common innovation infrastructure (Furman et al., 2002). The interactions that go beyond clusters constitute the third set of factors determining national innovation capacity, namely "the quality of linkages". The interactions among the actors of the national innovation systems involved in the development of new ideas allow innovation input to be translated into performance (output), i.e., commercialize new ideas. Without strong linkages between a common innovation infrastructure and cluster-specific environment for innovation, new scientific and technical ideas can diffuse to other countries instead of being exploited in the home country (Furman et al., 2002: 907; Porter and Stern, 2003: 6). Linkages can be supported and facilitated by different formal and informal institutions and by appropriate policy. They also depend to some extent on the structure of the university system and funding schemes for science and business (Furman and Hayes, 2004).

The concept of national innovative capacity fits well with the objectives of this study, as it covers key factors that determine innovation. Operationalization of these factors, which will be discussed in the next section allows a methodology to be built for innovation gap analysis.

Summing up, the literature on the innovation divide shows that countries differ in their access to knowledge and ability to use this knowledge for innovation. The innovation gap is a consequence of differences in the innovation capacity of countries and its determinants. The innovation gap may be a result of technological gaps but is not limited to divides in technology. This gap may occur in combination with technological dysfunction or separately, encompassing also lagging behind in non-technological innovations, such as new business models or social innovations. The environment in which the new idea is developed is an important element influencing innovation. Institutions, including tailored innovation policies encouraging entrepreneurial discovery and governance rules are of great importance for bridging the innovation gap.

2.2. Methodology and Data

The assessment of the size and scope of the innovation gap is conducted through a comparative analysis of the various indicators describing national innovative capacity. In our study, we adopt this methodological approach. Based on theoretical and empirical literature (Furman et al., 2002; Furman and Hayes, 2004; Porter and Stern, 2003; Rodríguez-Pose, 2020; Veugelers, 2016), we operationalize national innovative capacity using a set of indicators that are presented in Table 1. We group these indicators into two broad categories characterizing the ability to innovate and the innovative position. To get an overview of innovation capacity and compare China with selected countries, we employ two composite indices, i.e. the Summary Innovation Index for the European Innovation Scoreboard (European Commission, 2020) and the Global Innovation Index (Dutta et al., 2020). The synthetic indices are among the most comprehensive and most frequently used methods of measuring innovation. They usually consist of sub-indices relating to different aspects and stages of the innovation process. In particular, such indices refer to two key aspects of innovativeness of the economy: innovation capability and innovative position. Innovation capability is the potential of an economy or other entity (region, cluster, enterprise) to create and commercialize new ideas. It is an input approach to the issue of innovativeness. Innovative position, in turn, is a resultant approach indicating the effect of innovative activity resulting from the combination, in a specific economic and institutional environment, of the creativity of society with its financial resources (Weresa, 2014).

Based on the European Innovation Scoreboard methodology and data, indicators presented in Table 1 are used to measure the innovation capability and innovation position of China, the USA, and the EU. The relationship between these elements allows evaluating the efficiency of the innovation system, which reflects the minimization of resource consumption for obtaining intended results. This is based on the methodology used, e.g., in the Global Innovation Index 2018 report (Dutta et al., 2018) which measures the

Table 1 Indicators Used to Measure Innovation Capability and Innovation Position of China, the USA and the EU

	Indicator	Shortened name
Ability to innovate	New doctorate graduates per 1000 population aged 25–34	Doctorate graduates
	R&D expenditure in the public sector (percentage of GDP)	R&D exp. public sector
	R&D expenditure in the business sector (percentage of GDP)	R&D exp. business sector
	Private cofounding of public R&D expenditure (percentage of GDP)	Private funded public R&D
	International scientific co-publications per million population	International co-publ.
	Scientific publications among the top 10% most cited publications worldwide as percentage of total scientific publications of the country	Most cited publications
Innovation position	Public-private co-publications per million population	Public-private co-publ.
	PCT patent applications per billion GDP (in PPS)	PCT patents
	Trademark applications per billion GDP (in PPS)	Trademarks
	Design applications per billion GDP (in PPS)	Designs
	Exports of medium and high technology products as a share of total product exports	MHT exports
	Knowledge-intensive services exports as percentage of total services exports	KIS exports

Source: Authors' concept based on the European Innovation Scoreboard methodology.

innovation efficiency ratio (IER), calculated as the ratio of the output sub-index to the input sub-index, thus showing the result of innovation activity in relation to the expenditures incurred.

In order to assess if China is catching up with innovation leaders, i.e., the USA and the EU, σ-convergence (the coefficient of variation, i.e., σ-coefficient = √VAR/MEAN) is calculated. σ-convergence occurs when the observed variable differential between countries, measured by, e.g., the standard deviation, decreases over time.

Data for the analysis are derived from the European Innovation Scoreboard, received from the European Commission on 22 January 2021. Our analysis covers the years 2012–2019.

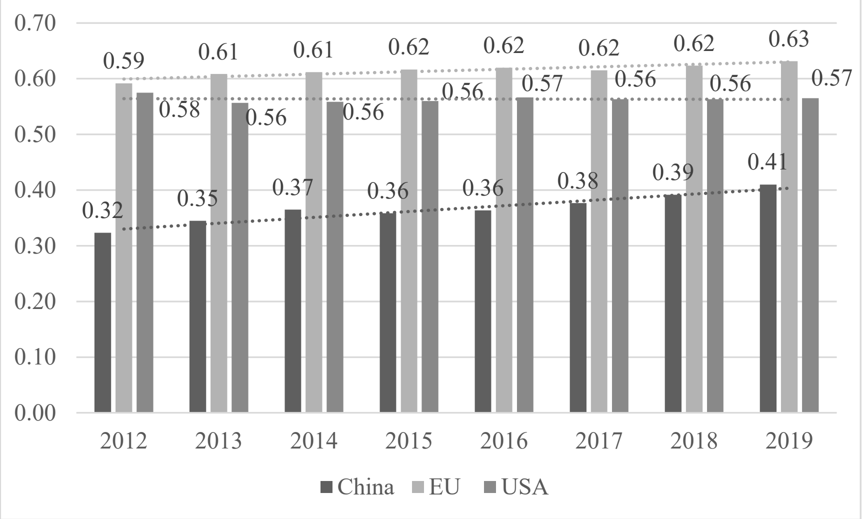
Following the statistical analysis aiming at the diagnosis of the innovation divide between China and the USA and the EU, the factors affecting innovative capabilities were examined and discussed, based on the available evidence presented in the empirical literature, and investigation of Chinese statistical data. The additional research method used was that of individual in-depth interviews (IDI) with four experts in innovation and the Chinese economy, involving two academics from China (Beijing and Chengdu), an academic from Europe, and a senior staff member of the Economic Section of the Polish Embassy in Beijing, China. The interviews were conducted via phone and in one case via email in July–August 2018 and in March 2021.

3. Results

Analyzing calculations for the ability to innovate (Figure 1), the input subindexes for the USA and the EU are significantly higher than for China, but in a dynamic perspective the Chinese economy catches up towards these two developed economies. The input subindex for China increased from 0.32 in 2012 to 0.41 in 2019, whereas in the EU it grew from 0.59 to 0.63 and in the USA it went down from 0.58 to 0.57.

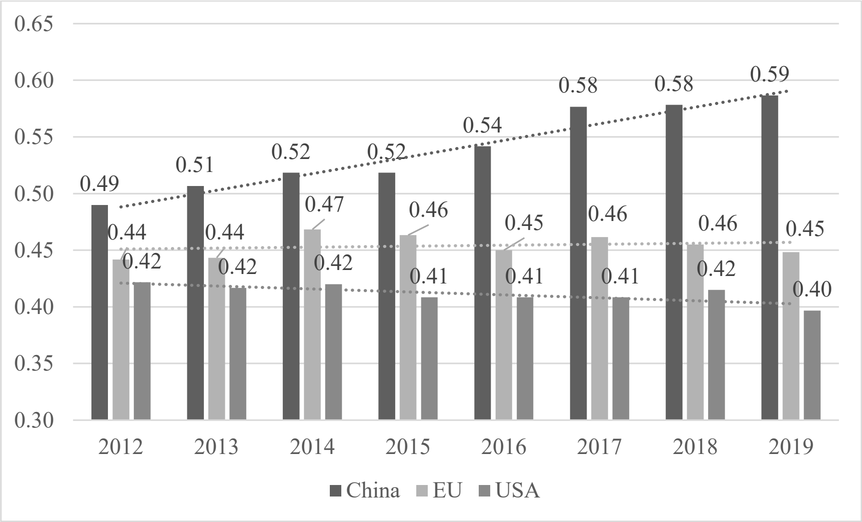
Different patterns are observed for the innovative position (Figure 2), in which China takes the lead among the analyzed countries. Additionally, China

Figure 1 Values of Input Subindexes for China, the USA and the EU



Source: Authors' calculations based on European Innovation Scoreboard data received from the European Commission.

Figure 2 Values of Output Subindexes for China, the USA and the EU

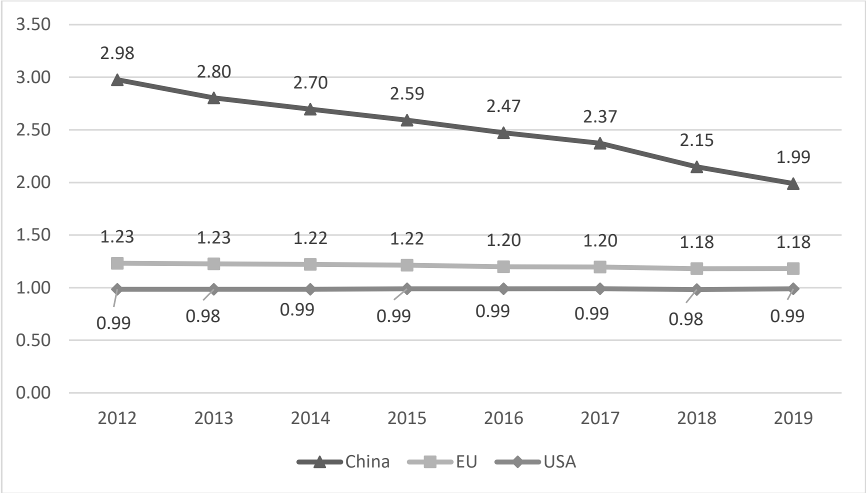


Source: Authors' calculations based on European Innovation Scoreboard data received from the European Commission.

experienced the fastest increase in the output subindex (from 0.49 in 2012 to 0.59 in 2019), whereas in the EU it rose from 0.44 to 0.45 and in the USA it dropped from 0.42 to 0.40.

The values of the innovation efficiency ratio (IER), calculated as the ratio of the output sub-index to the input sub-index, are presented in Figure 3.

Figure 3 Values of Innovation Efficiency Ratio for China, the USA and the EU



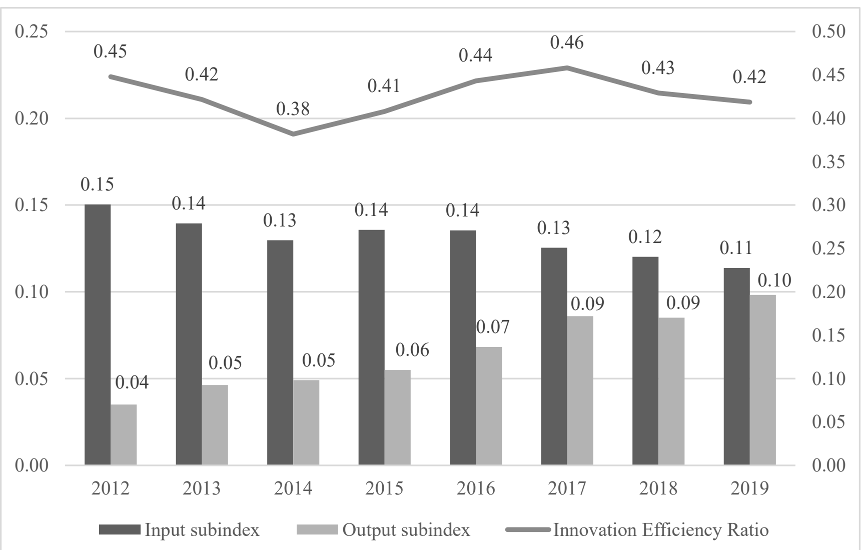
Source: Authors' calculations based on European Innovation Scoreboard data received from the European Commission.

Throughout the whole analyzed period, the highest values of the IER were achieved by China, which reflects its strong lead in the innovation position and shows high results of innovation activity in relation to the expenditures incurred. However, the IER for China diminished from 2.98 in 2012 to 1.99 in 2019, thus moving closer to that of the USA (in which it remained fairly stable around 0.99) and the EU (where it went down from 1.23 to 1.18 in the analyzed period).

Dynamics of the innovation divide in the world economy is analyzed by measuring σ-convergence (Figure 4). The calculations show σ-convergence in the ability to innovate between China, the USA, and the EU, as the standard deviation for input subindexes decreased from 0.15 in 2012 to 0.11 in 2019. At the same time, there was divergence in innovative position of the analyzed economies, as the standard deviation for output subindexes increased from 0.04 to 0.10. As for the innovation efficiency ratio (IER), the dispersion of the values for this indicator diminished during the period under analysis (standard deviation diminished from 0.45 to 0.42), indicating σ-convergence between China, the USA and the EU.

These results confirm that in the period 2012–2019 China managed to narrow its innovation gap with both the EU and the USA regarding the ability

Figure 4 σ-convergence of Input Subindexes, Output Subindexes and Innovation Efficiency Ratios (IER) for China, the USA and the EU in 2012–2019



Source: Authors' calculations based on European Innovation Scoreboard data received from the European Commission.

to innovate, but did not reduce the innovation gap regarding its innovative position measured by output. Nevertheless, when taking into account both inputs necessary for innovation and innovation outputs produced in the country, a catching up process with the EU and the USA in terms of overall innovation capacity was observed in China during the analysis period. These results also show that the pace of catching up with innovation leaders can be sped up when China is able to translate innovation inputs more efficiently into outputs. In this context, a focus for the discussion should move to factors facilitating successful reduction of the innovation gap in China, and they are studied in depth in the next section.

4. Discussion: Factors Affecting China's Innovation Capacity

The results of our analyses have shown a convergence between China and the world's innovation leaders regarding the ability to innovate. According to the concept of innovative capacity used as a framework for our analysis, the key factors contributing to this process may be found in the country's innovation infrastructure, including science, technology and innovation policy, R&D expenditures, human capital development, as well as the environment for entrepreneurial capacity-building in clusters and highly specialized industries. These factors and their development in China are discussed in this section in order to identify which of them have been of key importance to narrowing the innovation gap towards the USA and the EU.

4.1. Government and Policy Framework

China, as many East Asian economies, uses state capacity, proactively engaging in building its economy's development path (Dent, 2018). China's government has provided a stable environment for the development of innovation in selected technologies due to long-term science, technology and innovation (STI) policies and innovation-related guidelines included in the Five-Year Plans. The central government develops research and development (R&D) goals and provides financial support. In spite of some criticism as to the ability of government officials to select industries with a future economic potential, especially in hi-tech industries that change dynamically, as well as inefficiencies in the usage of public funding for R&D, the government has been a major actor driving the development of innovative capabilities in China. China's government has been setting up science and technology (S&T) programs and creating innovation infrastructure such as science parks, incubators and high-tech development zones in order to enhance linkages between key national innovation system actors, namely industry, universities and public research institutes. The central government's industrial policies and Five-Year Plans set guidance for industry as well as future and current students as to the areas that are supported by the government and where funding and thus career opportunities will be available. It is an important tool of the state to mobilize human capital (domestically and from abroad) and material resources for the realization of its goals.

Recognizing the gap with the world's innovators, Chinese authorities have pursued an accelerated catch-up strategy, which after 1978 meant gaining access to foreign technology by requiring foreign direct investment to be contingent on investors entering into joint ventures with local partners (forced technology transfer agreements). This has been accomplished since the early 2000s through Chinese companies' foreign technology acquisitions and sourcing, as well as commercial cyber espionage to gain access to frontier technologies and know-how (Laskai, 2018). Another way is to develop indigenous technologies and push for leadership in emerging industries, such as 5G and AI, in which China has already demonstrated innovation.

At the operational level, the major funding agencies in the Chinese innovation system are the Ministry of Science and Technology (MoST), the National Natural Science Foundation of China (NSFC), and the China Scholarship Council (CSC) affiliated to the Ministry of Education (MoE). In addition, the Chinese Academy of Sciences (CAS) runs programs supporting the researchers in R&D activities, with strong focus on engaging them in international cooperation. In China, regional innovation policies, similar to those in the European Union, play an important role. Provinces and municipalities, in general, have a high level of autonomy in this area, and subnational governments contribute a significant portion of total public R&D investment. There is a significant concentration of research investment in China's east, and there are also significant regional agencies that provide science and technology funds, such as the Beijing Municipal Commission of Science and Technology (BMCST), the Science and Technology Commission of Shanghai Municipality (STCSM), or the Guangdong Provincial Department of Science & Technology (GPDST). One of the key priorities in the activities of these agencies is to promote international scientific collaboration.

The study conducted by Guo et al. (2016) on one of the Chinese innovation policy instruments, the Innovation Fund for Small and Medium Technology-based Firms (Innofund), demonstrated that supported companies produce significantly higher technological and commercialized innovation outputs than non-assisted companies and the same enterprises before receiving funding. Innofund is China's largest government R&D program, supporting small and medium-sized businesses in their R&D efforts. The findings of the study also revealed that the switch from centralized to decentralized governance of this instrument in 2005 had a positive impact on the program's effectiveness. The study by Howell (2016) revealed that access to financial capital, which could be boosted by a lower corporate tax rate for private businesses, is a critical factor influencing Chinese firms' innovation efforts. In the long run, market failure caused by underinvestment in the private sector reduces the success of more R&D-intensive businesses, resulting in lower sales of new products and processes.

Strengthening China's science base through the development of large research infrastructures is another important driver of the country's increased innovation potential. They are an important part of China's national innovation system, with the government investing heavily in them (Chen, 2011). These types of infrastructures are characterized by a policy of open access based on scientific merit. Many of them have been organized to host foreign researchers and experiments of international teams (Marcelli, 2014), which was successful, as they have attracted researchers from around the world (Appelbaum et al., 2018: 114). Developing research infrastructures is a great contribution to increasing the R&D base in the economy and it boosts the innovative ability of the country. This process is fueled by the Knowledge Innovation Program (KIP) of the Chinese Academy of Sciences (CAS), which is a giant program aiming to narrow the science and innovation gap with leading countries (Liu and Zhi, 2010).

4.2. R&D Expenditures

China's spending on R&D has increased substantially since the beginning of the 1990s. In 2019, China's R&D spending as a share of GDP amounted to 2.23%, surpassing that of the EU (2.19%) and getting closer to the US level (2.8%). The spending on basic research out of the total R&D expenditures was relatively low at 5% in 2015, increasing slightly to 6% in 2019, while in the USA and Japan it accounted for 15% (National Bureau of Statistics of China, 2020). Increases in R&D spending are mostly generated by the business sector, which records higher annual increases of its spending on R&D (13% in 2017 y-o-y) than government research institutes (7%) and higher education entities (5.2%) (Xinhua, 2018).

4.3. Improving Quality of Higher Education

From the very beginning of reforms and opening-up, China focused on reforming the educational system to improve its quality, which nowadays has become a strategic priority. The latest reforms aim at diversity of education with the promotion of the humanities subjects, decreasing study burden, development of cognitive skills, enhancing the quality of higher education. In order to achieve that, China promotes the development and appeal of vocational and lifelong learning, tries to create a vast pool of quality teachers, promotes the teaching profession with a remuneration system based on performance, develops talent through linking creative students with business, encourages university researchers to cooperate with industry, develops and attracts new human resources, including foreigners by facilitating the process of obtaining permanent residency (China, 2016).

The reforms have already started to bear fruit as China recorded rising literacy rates and higher education enrolment (Crescenzi et al., 2019). In 2020, China scored 67 points out of 100 in "Updating education curricula and expanding investment in the skills needed for jobs and 'markets of tomorrow'", overtaking Germany (61.4), Japan (51.3), but trailing the USA (68.2). In the period 2016–2020, the skill set of university graduates increased by 14%, which was the second best result among G20 countries (Schwab and Zahidi, 2020: 22). Overall, the above numbers imply a strong trend in improvements of quality education in China, their adjustment to market needs and increasing availability of skilled labour in the near future. Nevertheless, China shows signs of a lack of an adequate number of specialized workforce, for example in artificial intelligence (AI), in which it aims to take the global lead (Ives and Holzmann, 2018).

China's leading universities have improved the quality of teaching and research. According to the World University Ranking issued by the Times Higher Education, between 2005 and 2021 the number of Chinese universities that made it to the world's top 100 increased from five to six. These universities also rapidly improve their position: Peking University (from 29th position in 2016 to 23rd in 2021), Tsinghua University (35th to 20th in 2021), Fudan University (155th to 70th), University of Science and Technology of China in Hefei (153rd to 87th), Shanghai Jiaotong University (201–250th to 100th), Zhejiang University (201–250th to 94th). As of today, these universities represent 6% of higher education institutions in China, receive 70% of R&D funding, produce about 30% of undergraduate students, 60% of graduate students and 80% of PhD students (Veugelers, 2017).

4.4. Human Resources for Innovation

China's progress in developing innovations depends to a great extent on the availability of skilled labour force in S&T fields. As a result of education reforms, Chinese high school students from Beijing, Shanghai, Jiangsu, and Guangdong have been improving their results in the Program for International Student Assessment (PISA) test of average mathematics literacy assessment, with a score of 531 in 2015, which was similar to Japan's (532) and higher than for South Korea and Switzerland (National Science Board, 2018). These high school students are the prospective pool of talent for STI industries.

China has made rapid progress in developing science, technology, engineering and mathematics (STEM) graduates. It was second in the world behind India in awarded bachelor's degrees in science and engineering (S&E), with 22%, compared with the latter's 25% (EU accounted for 12% and the USA for 10%). In the period 2000–2014, the number of awarded bachelor's degrees in S&E grew more than 350%. Bachelor degrees in non-S&E majors grew by 1200% during that time, indicating capacity building also outside of S&E (National Science Board, 2018). In terms of the number of doctoral awards in S&E, China became third in the world in 2001 behind the EU's top eight innovative countries and the USA (overtaking Japan), approaching the US level in the period 2009–2011 (impressive as China started from a low number of around 8,000 and in 2014 around 35,000) and losing the trend afterwards till 2015. As of 2015, China was second in the world behind the EU in the estimated number of researchers (National Science Board, 2018).

Another source of high-skilled labour are the Chinese educated or working overseas as well as foreign talent, but this pool of labour depends on China's ability to attract, produce and retain top-level researchers. The number of students studying abroad has been rising since the start of reforms in 1978, from 860 in 1978 to 38,989 in 2000 to 662,100 in 2018. The number of returnees from overseas studies increased from 23.4% in 2000 to 79% in 2017, 78.4% in 2018 (National Bureau of Statistics of China, 2020), which is a result of greatly improved living conditions and greater career opportunities available nowadays in China. But recently, it is also due to an increasingly unfriendly attitude towards Chinese scientists and students in the USA since the start of the trade war in 2018.

However, China's efforts (100 Talents, 1000 Talents programs) at encouraging overseas mainland Chinese scholars to return to China have been a limited success, with some of them returning only part-time but not permanently. Domestic institutions in academia such as local power holders resisting change and competition from abroad, "'complicated nature of human relations' in Chinese society" requiring managing relationships (*guanxi*), excessive administrative burden, nepotism, seniority and gender biases are not only reasons for foreign scholars to be unwilling to return permanently, but also hinder the effective utilization of local talent (Zweig et al., 2020).

4.5. Development of Clusters and Highly Specialized Industries

The regional perspective is critical to innovation because of the increasingly recognized importance of proximity in stimulating innovation processes, and an observed strong geographical polarization of innovation activity in specific regions (Autant-Bernard et al., 2012), a trend that is particularly noticeable in China (Crescenzi et al., 2012). In China, industrial clusters have exploded in size and quantity in recent years, particularly in the more developed coastal regions (Kang and Ramirez, 2007). As the research by Herrerias and Ordóñez (2014) demonstrated, during the post-reform era (after 1978), the growth rate of the stock of physical capital in the eastern provinces was twice as high as in western provinces, and one and a half times greater than in the central regions. Clusters are also a key component of the Belt and Road Initiative (BRI), which aims to improve international and interregional collaboration throughout Eurasia, by, e.g., strengthening transport linkages. As the investments will become platforms for clustering of industries, the key elements of the new Silk Road will be not only emerging logistic and transport clusters but also international networks of local cluster structures integrated across the whole value chains in different areas (Kowalski, 2019).

Innovative clusters or even cluster cities developed on the basis of special economic zones and large inflows of foreign direct investment have been sources of technology and managerial expertise. Over decades, they produced domestic companies that undertook foreign expansion, often seeking access to foreign technology and know-how resulting in the reverse resource transfer effect forming a vibrant competitive environment. As of 2017, the leaders in inward FDI and outward FDI stock were the coastal provinces of Guangdong, Shanghai, Zhejiang, Shandong, Beijing and Jiangsu (National Bureau of Statistics of China, 2020). China's innovation landscape is however highly concentrated in three cities – Beijing, Shanghai and Shenzhen, which account for 66.3% of United States Patent and Trademark Office (USPTO) patents (Jiang et al., 2020), host emerging sectors (Zhao et al., 2010), and lead in international inventive and scientific collaboration (WIPO, 2019). Their followers are Guangzhou, Chengdu, Xi'an, Tianjin, Chongqing, Suzhou, Hangzhou, Nanjing, Wuhan, Ningbo and Dalian (Fudan Institute of Industrial Development, Di Yi Caijing Yanjiuyuan Research and Research Institute of Chinese Economy Fudan University, 2017; Wang et al., 2015; WIPO, 2019). Beijing, Shanghai, Shenzhen, Guangzhou as well as Suzhou and Nanjing offer high incomes compared to other regions, attracting talent and other resources. At the same time, their local authorities implement policies aimed at building ecosystems of innovation attractive for living for domestic and foreign professionals and their families as well as for innovative ventures (Appelbaum et al., 2018; Conlé and Taube, 2012). Local governments provide financial support to innovative companies, attract recognized domestic and foreign universities to locate their branches there, and improve living conditions by, for example, reducing air pollution.

Beijing's Zhongguancun cluster specializes in information and communication technology (Internet, hardware and software) and artificial intelligence

(AI). Shanghai is a cluster for life sciences (biotechnology) and electronics. Shenzhen-Guangzhou-Dongguan-Hong Kong is a cluster of technology (especially information and communication technology, next generation Internet, semiconductors and electronics hardware), AI, electric cars and rechargeable batteries and Internet start-up firms (Prud'homme and Von Zedtwitz, 2018).

4.6. Venture Capital

China has been attracting increasing volumes of venture capital and has become second in the world behind the USA in attracting early and later-stage venture capital funding. Yet the majority of venture capital in China comes from the government (Appelbaum et al., 2018). Government provides venture capital in the form of guidance funds used to establish new funds that are combined with private capital to support firms from selected emerging industries. By 2016, more than 1,000 vehicles utilizing government budget-seeds were established, which opted for a total social capital of RMB5.3 trillion (USD798 billion) that year, an increase of 30% and 144% y-o-y, respectively. The above-described developments resulted in a rapid increase of venture capital available in China, especially since 2014 when Li Keqiang's initiative of mass entrepreneurship and innovation was announced at the Davos Forum in Tianjin.

Besides government R&D funding, China's innovative firms, especially private ones, often utilize alternative financial sources such as friends, family members, crowdfunding, and private loans. Chinese successful entrepreneurs such as Jack Ma, founder of Alibaba, also seek opportunities for investment in innovative projects (start-ups) setting up their own venture capital funds giving rise to the growth of domestic venture capital.

4.7. China's Increasingly Sophisticated Domestic Market

The sheer size of China ensures scale not possible elsewhere in the world. Less stringent regulations than in developed markets allow for fast and relatively less costly launch of new products and their testing on the market, while the manufacturing ecosystem covering almost all industries makes process innovations easy to introduce. Such a market provides huge support to entrepreneurs looking for niches, qualified S&T talent, patients for drug tests, etc., and to the development of customer-based and efficiency-driven types of innovation (Williamson, 2016). The intensity of competition has resulted in a high speed of change and adaptation of local firms. The Chinese government has encouraged risk-taking, innovation and entrepreneurship (Dai et al., 2019). In 2020, in terms of "incentivizing and expanding patent investments in research, innovation and invention that can create new 'markets of tomorrow'" China scored 50 out of 100 points, overtaking Germany (49.2), but falling behind Japan (54.7) and the USA (57.3) (Schwab and Zahidi, 2020). The majority of China's population dreams of becoming rich, encouraged by successes of such business people as Jack Ma, founder of Alibaba, or Ma Huateng, co-founder of Tencent. This is reflected in Chinese people's propensity towards entrepreneurial risk, which, after the global financial crisis till 2016, has been greater than in Germany, Japan and France, but lower than in the USA. It stagnated and was lower than in Germany till 2019, to change again in 2020, the pandemic year, when people's appetite for risk increased (Schwab and Zahidi, 2020).

China's middle class of 430 million people accounted for 6.9% of the global private consumption share in 2016 (doubled in the last decade). These consumers are open to new products, brands and willing to co-develop. The environment of entrepreneurial drive combined with intense competition and huge, open-to-innovation customer base, is supportive of testing and adapting products to changing consumer needs. Having experienced dramatic and rapid changes during the last five decades made Chinese people easily adopt and adapt to innovations. At the same time, the Chinese enjoying increasing living standards expect companies to engage in protecting and improving the environment, which pushes firms for ecological and health innovations (Chen et al., 2017).

5. Conclusion

Although China has historically been placed in the group of countries with developing innovation systems, which are technology takers and followers, the analysis undertaken in this study demonstrates that it is in the process of catching up with the European Union and the USA in terms of innovativeness level. In particular, σ-convergence can be observed in innovation capabilities between China, the USA and the EU, which confirms an increasing innovation potential of the Chinese economy. The research presented in this paper allows the key factors contributing to this process to be identified, which may be found in science, technology and innovation policies, increased R&D expenditures, human capital development, and the development of clusters and highly specialized industries.

China's government financial and policy support driven by determination to shift the economy towards reliance on innovations, which is necessary for stable economic growth that provides legitimacy for Chinese leaders, constitutes a stable ground for the country's development of innovative capacity. The government continuously increases R&D funding, spending on advanced research infrastructures, develops human capital through improvements in the quality of higher education and mobilization of R&D human capital domestically and from abroad. It encourages entrepreneurial ventures following the old slogans of Deng Xiaoping "Getting rich is glorious". Risk takers and innovative endeavours are rewarded by the possibility to become rich, which is a dream for many Chinese. This combination of government support and people's desire provides a fertile ground for the development of a sustaining innovation type, that is, improvements of already existing solutions. The majority of Chinese firms continue to rely in their innovation activities on foreign technology, which is China's important source of advanced technologies and ideas (Losacker and Liefner, 2020). Basic research, which is the foundation of breakthrough innovations and innovation leadership necessitates strong intellectual property rights (IPR) protection, which still falls behind the standards of innovative countries (Appelbaum et al., 2018; Schmid and Wang, 2017). The institutional environment in China's universities, which perform basic research, which is to a great extent governed by relationships, may hinder the utilization of talent and efficient development of basic research necessary for the development of sustainable innovative capacity.

The study also has implications for nations with growing innovation systems, such as those in Central and Eastern Europe, which are attempting to construct a knowledge-based economy and catch up with world innovation leaders. Closing the technical gap through absorbing external technology and developing indigenous capabilities to use and improve those technologies is critical to these countries' development success. This necessitates significant public investment in R&D, as well as increased R&D spending in the private sector, as private R&D spending is more effective in terms of commercialization of research discoveries, which is crucial for innovation.

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