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INNOVATION DIVIDE IN THE WORLD ECONOMY: CHINA'S CONVERGENCE TOWARDS THE TRIAD

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Abstract. The objective of this article is to assess the dynamics of the innovation divide between China and the Triad, as well as to determine the factors that influence its evolution. The Triad consists of three economies traditionally dominating the world economy: the United States, the European Union, and Japan. The methodology involves the decomposition of the innovativeness of the economy into innovation capability, innovation position, and the relationship between them, which indicates the efficiency of the innovation system. The analysis of dynamic indexes and σ-convergence in all these components confirms that the global economy has been gradually losing clear polarization into innovation leaders, found among developed countries and innovation followers, which have traditionally been associated with developing nations. In addition to demonstrating fast improvement in the Summary Innovation Index of China towards the Triad, the paper has a clear contribution by showcasing China's improvement through the decomposed factors of the innovativeness of the economy. In comparison with the Triad, China has a proportionally higher innovation position and efficiency of the innovation system and a lower level of innovation capacity. This demonstrates its dependence on external sources of innovation and international technology transfer, e.g. through foreign direct investments.

Keywords: innovation divide, innovation capability, innovation position, innovation efficiency, convergence, the Triad, China.

JEL Classification: O3, O1, O2.

Introduction

In the last few years, innovation has become one of the key economic issues. According to many economic theories, such as the economic growth theory (Romer, 1990), the new economic geography (Krugman, 1998), or the concept of the knowledge-based economy (Foray & Lundvall, 1998), technological advancement is among key factors of economic development. With the rise of the knowledge economy, a country's ability to innovate is becoming increasingly important in fostering social and economic progress (Furman et al., 2002). Spe-

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cial importance is played by the emergence of the novel digital technologies, which has been transforming economies and entrepreneurship in significant ways (Nambisan et al., 2019).

Traditionally, technological progress has been the domain of developed economies, which mostly include the Triad. In the Eurostat glossary, the Triad refers to the three centers which had dominated the world economy until the late 1990s: the United States (the US), the European Union (the EU), and Japan; or, more broadly, North America, Western Europe, and Japan. However, the Triad's collective economic weight has declined in the 21st century due to the rapid development of the so-called BRIC countries, which incluse Brazil, Russia, India, and China. Innovation opens new opportunities for economic development in emerging economies to promote sustainable growth, fueled by the diffusion of digital technologies (Kaplinsky & Kraemer-Mbula, 2022). Hence, a study problem gaining attraction in international economics is that of the structural changes in the world economy, particularly the movement of industrial innovation activity, including high-tech sectors, to emerging markets, primarily China. While formerly R&D-led technological growth was localized mostly in high income countries, which created the majority of innovation (Furman & Hayes, 2004), we can now see the establishment of innovation hubs in emerging economies, with China leading the way in innovation performance. The substantial improvement in the innovation performance makes China an obvious sample economy to be studied for relevant research on the theme of innovation (Wen et al., 2018). A considerable shift in the geography of innovation offers a challenge for established economies, such as the EU, Japan, and the US, which may lose their knowledge-based economic advantages.

The study focuses on the convergence between China's and the Triad's innovation performance. The key objective is to assess the dynamics of the innovation divide between China and the Triad, as well as to determine the factors that influence its evolution. The timeframe of the analysis covers the period 2014-21 as 2014 is the initial year for the programming period and the start date of the collection of data in European Innovation Scoreboard 2021. The research questions are:

1. What is the innovation gap between China and the Triad, and how has it evolved throughout the analyzed period?
2. How fast has China been converging to developed economies in innovation performance?
3. What drives innovation performance in the Chinese economy?

The structural changes in the global innovation system, as well as the need to find answers to the research questions outlined above, have led to the formation of the following hypotheses: the Triad leads China in terms of innovation performance, but the innovation divide between these economies has been narrowing since 2014. The key drivers of China's convergence in innovation performance to innovation leaders are: increased investments in R&D, political, financial and regulatory support of the central government for innovative enterprises, improving the quality of higher education and the associated development of human capital and availability of R&D personnel, foreign direct investment (FDI) technological spillovers, and green innovation for low-carbon economic growth.

While the majority of the studies (Basel et al., 2021; Strielkowski & Höschle, 2016) focus on income convergence, this paper goes beyond GDP per capita and focuses on the innovation convergence, trying to answer the question of whether economies with lesser levels of innovation performance are able to catch up to leaders in innovation. This problem is analyzed through the prism of the experiences of China, where, since the reform in the early 1980s, technological and institutional innovations have been more active, and innovation has emerged as the most effective driving force in economic and social development (Lei et al., 2020). The novelty of this study is in the decomposition of innovativeness of the economy into innovation capability and innovation position, which enable the efficiency of the innovation system to be measured. The analysis is conducted from a dynamic perspective, which allows σ-convergence and the time variability of the examined phenomena to be measured by using dynamic indexes with variable and fixed bases.

1. Literature review

The global economy's innovation divide was studied by Sachs (2003) who noticed the underdeveloped nature of innovation systems in developing countries, or, even more specifically, the lack of such systems, which explains why innovation and technical advancement do not occur in huge areas of the globe. Innovating countries develop innovative technologies and then profit from their usage as well as royalties from their commercialization, whereas non-inventors must purchase the rights to use any such technology. Hence, innovation is perceived among the primary motivators for international competitiveness and economic development (Priede & Pereira, 2013).

Knowledge and innovation have been identified as developed nations' drivers of competitive advantage in recent decades. At the same time, cheap resources have been the primary determinant of competitive advantage for emerging countries, with China being the most notable example with its massive pool of low-cost labor, resulting in a focus on low-tech industries. This old international division of labor has experienced dramatic modification as a result of the geographical relocation of innovative manufacturing industries to emerging nations (Ebenstein et al., 2015).

Low innovation capabilities are one of the primary reasons that may push emerging economies into the middle-income trap (Kang & Paus, 2020). This term refers to nations that have seen rapid growth and so obtained the ranking of middle-income country (MIC) in a relatively short period of time but have failed to catch up to high-income countries (Glawe & Wagner, 2020). Recently, in addition to an established discussion on the innovation divide, there has been a growing interest in the digital divide (Dijk, 2020). Concerning this, Drori (2010) separates these two concerns, stating that they lead to two multiple policy tracks, dealing with the world's leaders and laggards as distinct entities with diverse logics.

The problem of the dynamics of the innovation divide and convergence in innovation performance is of particular interest when analyzing China, which has been seen predominantly as a country of imitation (Ahlstrom et al., 2018). It is commonly acknowledged that, in comparison to more developed countries, China as a transition economy lacks a mature innovation system with the necessary socio-cultural and legal institutions. The paradox is that China, despite its history of breakthrough inventions like the compass, paper or gunpowder, has been technologically lagging behind Europe since the industrial revolution (Ahlstrom et al., 2018). However, recent research on Chinese innovation and technical advancement has highlighted China's remarkable technological growth over the previous decade (Kaufmann, 2021; Veugelers, 2017). Lindtner investigates the shift of technological progress from the United States to China, demonstrating how China, long regarded as a country incapable of innovation, has lately come to be perceived as an innovative country, a place to "prototype alternatives to existing models of modern technological progress" (Lindtner, 2020, p. 6). At this point, successfully maximizing the allocation of innovation resources and improving innovation efficiency are critical concerns confronting China's implementation of an innovation-driven strategy (Wang et al., 2021). Hence, the importance of this study is to analyze the progress in innovation performance of the Chinese economy and to identify the determinants of the recent catch-up with developed economies, like the EU, Japan, and the US.

According to the findings of empirical research conducted by Zhang (2021), the key drivers of Chinese innovativeness were related to investment in innovation, government assistance, and spillover effects resulting from foreign direct investment (FDI). Furthermore, Tyfield (2018) mentions disruptive low-carbon innovations in China, as well as archetypal examples of Chinese digital giants, such as Baidu, Alibaba, and Tencent, which are genuinely disruptive in ways that Silicon Valley is not. Dynamic processes of developing China's inventive potential provide a strong foundation for future convergence and catching up to the more developed economies such as the European Union (Kowalski, 2020). However, several studies have shown that massive and rising resources for science and technology deployed in China have resulted in increased R&D production (such as patents and scientific articles), but have not yet translated into adequate gains in innovation performance (Schmid & Wang, 2017).

Research by Wang et al. (2016) indicates that government science and technology policy has a substantial impact on enhancing innovation capability in China. These findings suggest that the focus of Chinese policy is mostly on directing rising innovation spending and that it is time to shift focus. China is transitioning from focusing on growth pace and scale to targeting efficiency and quality in terms of innovation output. In consequence, more emphasis should be placed on the creation of an innovative environment, and China's policy should shift from supporting knowledge base to stimulating interactions among the actors of the innovation ecosystem.

2. Research methodology

Due to the complexities inherent in the innovation process, the measurement approaches and methodologies are constantly evolving. As there is no single general way for quantifying the phenomena of innovativeness, a variety of methods are used. There are three primary categories of innovation measuring metrics, according to Smith (2005, p. 152):

1) technometric indicators, which are used to measure and compare the dimensions of technical performance of a product or production process,
2) synthetic indicators developed as indexes calculated based on various subindexes, which are derived from a set of particular indications,
3) databases on various types of detailed issues related to innovation, which serve as the foundation for the calculation of additional indicators.

The synthetic indexes mentioned in point 2 are among the most extensive and widely used approaches to measuring innovation, as they demonstrate the ability to grasp the complexities of innovation processes. They typically include subindexes that correspond to various aspects and stages of the innovation process, starting from drivers of innovation (e.g. R&D expenditure), up to results of the innovative activities (like the share of high-tech product exports in total exports). Such indexes should, in particular, address two critical characteristics of innovation:

1) innovation capability (measured by the input subindex) – the ability of an economy to develop and commercialize new ideas;
2) innovation position (measured by the output subindex) – the entire effect of innovative actions carried out by firms operating in the economy over a particular period.

The analysis in this research is based on data that came from the European Innovation Scoreboard 2021, in which total innovation performance (covering both innovation capability and innovation position) is measured by the Summary Innovation Index (SII) based on individual indicators. The input layer (representing innovation capability) is mostly made up of variables that encourage innovation and activities that demonstrate how ideas are implemented in practice. The output layer (representing innovation position) is defined by effects that represent the outcomes of business-related inventive activities (Roszko-Wójtowicz & Białek, 2019). Following the European Innovation Scoreboard methodology, the indicators used in this study to measure input and output subindexes are presented in Table 1 and Table 2.

Table 1. Indicators used to measure innovation capability (input subindex) of an economy (source: author's concept based on the European Innovation Scoreboard 2021 methodology)

Indicators		Interpretation and justification for selection
Input 1	Population aged 25–64 having completed tertiary education	General indicator of the supply of advanced skills.
Input 2	International scientific co-publications (per million population)	A proxy for the quality of scientific research as collaboration increases scientific productivity.
Input 3	Scientific publications among the top 10% most cited publications worldwide as a percentage of total scientific publications of the country	A measure for the efficiency of the research system, as highly cited publications are assumed to be of higher quality.
Input 4	R&D expenditure in the public sector (percentage of GDP)	R&D spending is critical for enhancing production technology and increasing growth.
Input 5	Direct government funding and government tax support for business R&D (percentage of GDP)	Direct funding is well captured in the official data and over time, many countries have introduced R&D tax incentives.
Input 6	R&D expenditure in the business sector (percentage of GDP)	It is especially crucial in science-based industries (e.g. pharmaceuticals) where most new knowledge is created in R&D laboratories.
Input 7	Public-private co-publications per million population	This metric measures public-private research collaborations that result in academic publications.

Table 2. Indicators used to measure innovation position (output subindex) of an economy (source: author's concept based on the European Innovation Scoreboard 2021 methodology)

Indicators		Interpretation and justification for selection
Output 1	PCT patent applications per billion GDP (in PPS)	The number of patents is one of the measures of the rate of new product innovation.
Output 2	Trademark applications per billion GDP (in PPS)	Trademarks are an essential indicator of innovation, particularly in the service industry.
Output 3	Design applications per billion GDP (in PPS)	Design is transforming the way companies create value.
Output 4	Exports of medium and high-technology product exports as a share of total product exports	The measure of the ability to commercialize R&D results in international markets. It also reflects product specialization by country.
Output 5	Knowledge-intensive services exports as a percentage of total services exports	It shows the capacity to export high-value-added services and successfully participate in knowledge-intensive global value chains.
Output 6	Air emissions by fine particulates (PM2.5) in industry	An important measure reflecting eco-efficiency of the innovation system.
Output 7	Development of environment-related technologies, percentage of all technologies	An indicator measuring the rate of creation of eco-innovation in a country.

The values of the indicators in Table 1 are normalized and range from 0 to 1, with higher numbers indicating better performance in the underlying categories. Normalized scores are calculated by transforming real data so that the minimum value across all countries and years is 0 and the maximum value equals 1. The input subindex is measured as a mean of all seven indicators used to measure innovation capability, whereas the output subindex as a mean of all seven indicators used to measure innovation position, as given by the following formulas:

$$\text{Input subindex} = \frac{1}{n}\sum_{i=1}^{n} Input_i; \quad (1)$$

$$\text{Output subindex} = \frac{1}{n}\sum_{i=1}^{n} Output_i. \quad (2)$$

Finally, recognizing and assessing the relationship between innovation capacity and innovation position enables the efficiency of the innovation system to be measured, which indicates a reduction in resource use while attaining the desired goals. This corresponds to the development of fully operational networks and markets, which can have a substantial influence on the efficiency of the innovation effort (OECD, 2010). It enables the evaluation of the innovation system' effectiveness that indicates how well an economy converts inputs into outputs (Nasierowski, 2019). Different strategies for measuring innovation efficiency have been studied by academics. For example Chen and Guan (2012) used a relational network data envelopment analysis to conduct a comprehensive investigation of the innovation efficiency of Chinese regional innovation systems, whereas Bai (2013) studied main elements influencing regional innovation efficiency in China. In this article, the methodology used is comparable to that used in the Global Innovation Index 2018 report (Dutta et al., 2018), which measures the Innovation Efficiency Ratio (IER), calculated as the ratio of the output subindex to the input subindex, thus showing the result of innovation activity in relation to the expenditures incurred.

The efficiency of the innovation system is measured by the Innovation Efficiency Ratio (IER), given by the following formula:

$$\text{IER} = \frac{\text{Output subindex}}{\text{Input subindex}}. \tag{3}$$

In order to test if countries with lower innovation performance catch up with innovation leaders, σ-convergence is calculated. σ-convergence is measured by the σ-coefficient, which may be expressed in the standard deviation, i.e.:

$$\sigma\text{-coefficient} = \text{SD} = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}, \tag{4}$$

σ-convergence occurs when the observed variable differential (standard deviation) between countries decreases over time. In addition, to examine the variability of analyzed phenomena in time, the dynamic index with variable base ($I_{t/t-1}$) and dynamic index with fixed base ($I_{i/f}$) (f denotes the base year of the analysis) may be computed using the following formula after Anghelache and Manole (2012):

$$I_{t,t-1} = \frac{X_t}{X_{t-1}} * 100\%; \tag{5}$$

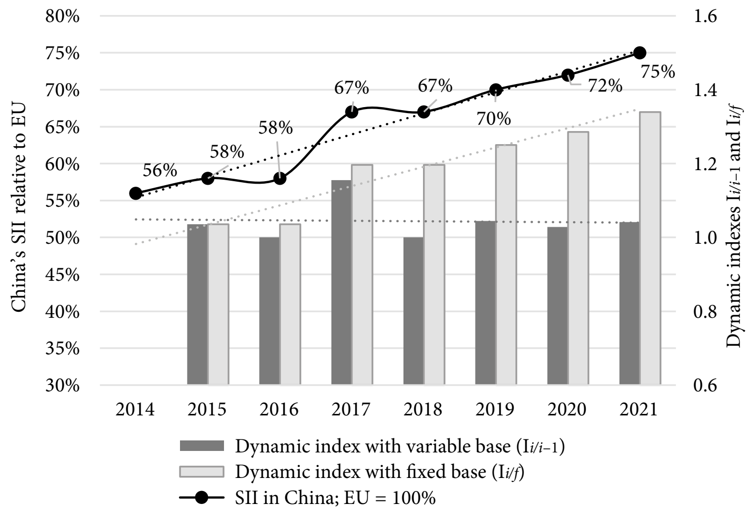
$$I_{t,f} = \frac{X_t}{X_f} * 100\%. \tag{6}$$

3. Empirical results and analysis

In the first stage, the dynamic analysis of the overall innovation performance of the studied economies is performed. For the clarity of the figures, the innovation performance of China is compared to the EU, Japan, and the US in three separate charts. China's innovation performance relative to the EU average level is presented in Figure 1.

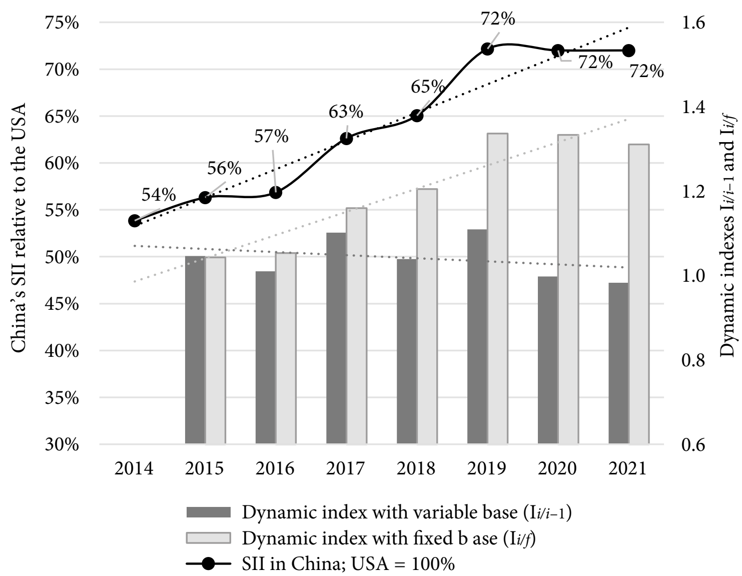
Scores in the above chart are obtained by dividing China's SII by that of the EU average and are expressed as a percentage. The data demonstrates that the Chinese economy's innovativeness, as judged by this indicator, has been progressing, rising from 56% of the EU average in 2014 to 75% in 2021. This corresponds to the rising average values of the dynamic index with fixed base as represented by the upward-sloping trend line, suggesting China's longstanding catch-up towards the EU innovation performance. However, the trend line for the dynamic index with variable base is downward-sloping, indicating that the pace of China's innovation convergence towards the EU is slowing down. A corresponding type of analysis is performed for the US as presented in Figure 2.

According to the data, the Chinese economy's Summary Innovation Index has risen from 54% of the US in 2014 to 72% in 2021. This corresponds to rising average values of the dynamic index with fixed base, as represented by the upward-sloping trend line, implying China's longstanding catch-up towards the United States in innovation. However, the trend line for the dynamic index with variable base is sloping downward, indicating that China's innovation convergence with the EU is slowing. A corresponding type of analysis is performed for Japan as presented in Figure 3.



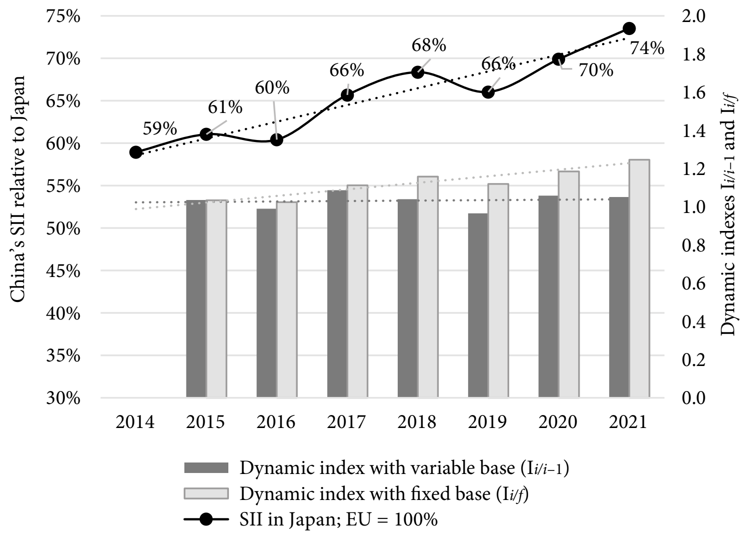
Trend line for SII: SII = 0.0285 Year + 0.5257
Trend line for $I_{i/F}$: $I_{i/iF}$ = 0.0523 Year + 0.9298
Trend line for $I_{i/i-1}$: $I_{i/i-1}$= −0.0013 Year + 1.05

Figure 1. China's innovation performance relative to the EU
(source: author's computations using data from the European Innovation Scoreboard 2021)



Trend line for SII: SII = 0.0302 Year + 0.5026
Trend line for $I_{i/F}$: $I_{i/iF}$ = −0.0055 Year + 0.9307
Trend line for $I_{i/i-1}$: $I_{i/i-1}$= 0.0073 Year + 1.0774

Figure 2. Innovation performance of the Chinese economy relative to the USA
(source: author's computations using data from the European Innovation Scoreboard 2021)



Trend line for SII: SII = 0.097 Year + 0.5661
Trend line for $I_{i/F}$: $I_{i/iF}$ = 0.0344 Year + 0.9541
Trend line for $I_{i/i-1}$: $I_{i/i-1}$= 0.0023 Year + 1.0212

Figure 3. Innovation performance of China relative to Japan
(source: author's computations using data from the European Innovation Scoreboard 2021)

The data demonstrates that the Chinese Summery Innovation Index has been converging towards the Japanese level, from 59% in 2014 to 74% in 2021. At the same time, the innovation performance of Japan has improved, from 95% of the EU average to 102% in 2021. It may be a sign of the recovery of the Japanese innovation system, which had proven its technical dominance, particularly during the Japanese miracle age, which lasted until the 1980s. The success of this country innovation is credited in part to Japanese management practices and efficient manufacturing processes. For example, Yusof and Othman (2016) pay attention to the leadership's impact on fostering creativity and innovation in organizations in Japan, highlighting the specificity of the Japanese system.

As presented in the research methodology section, the complex nature of innovative processes requires its decomposition into two elements: innovation capability and innovation position. The values of the input subindex, reflecting the innovation capability of the examined countries, are presented in Figure 4. Additionally, σ-convergence is analyzed to test if economies with lower innovation capability are catching up with innovation leaders. σ-convergence is measured by the standard deviation and it occurs when the observed variable differential between countries decreases over time.

When estimates of innovation capacity are performed, the input subindexes for the United States and the European Union are much greater than those for China. However, from a dynamic standpoint, we can see a convergence process for these three economies, which is indicated by a downward sloping trend line for standard deviation. This is primarily due to China, which has seen rapid development in its innovation capabilities during the last few decades. Economies with high innovation capability are characterized also by high absorptive capacity, seen as a key moderator in the knowledge formation process. The values of the output subindex, reflecting the innovation position of the analyzed countries, are presented in Figure 5.

We observe much smaller discrepancies in the values of the output subindex compared to the input subindex for the analyzed economies. Moreover, there is σ-convergence in in-

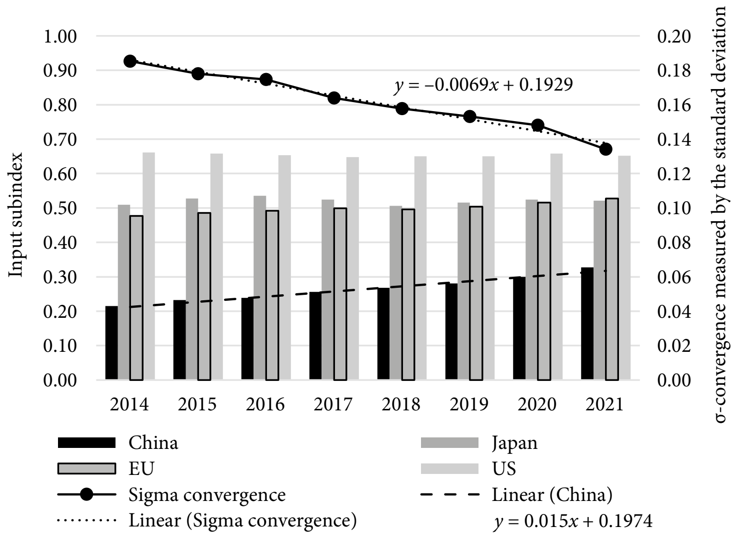


Figure 4. The values of input subindexes for China and the Triad: the EU, Japan, and the US (source: author's computations using data from European Innovation Scoreboard 2021)

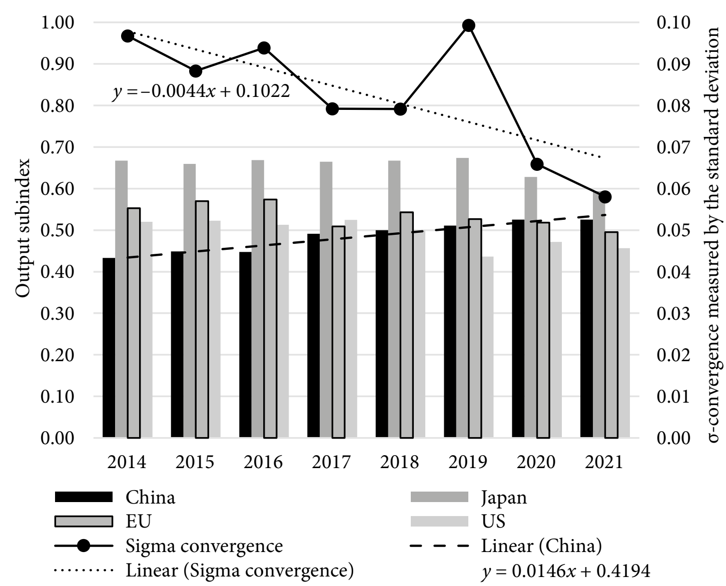


Figure 5. The values of output subindexes for China and the Triad: the EU, Japan, and the US (source: author's computations using data from the European Innovation Scoreboard 2021)

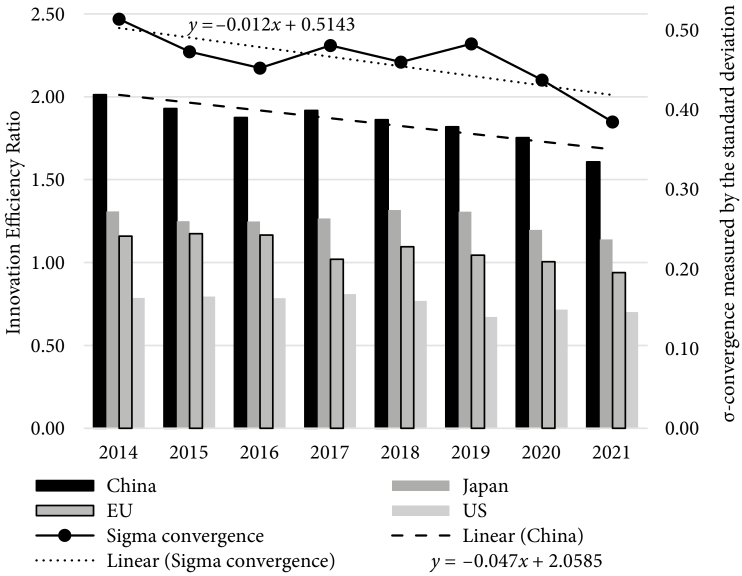


Figure 6. The values of the Innovation Efficiency Ratio for China and the Triad: the EU, Japan, and the US (source: author's computations using data from the European Innovation Scoreboard 2021)

novation position in the analyzed period, as indicated by the downward-sloping trend line for this indicator. The fastest increase in innovation position is observed for China, which takes a lead over the EU and the USA in this respect in 2020 and 2021, but not over Japan. Contrasted with the lowest innovation ability level in China, this leads to an interesting question about innovation efficiency in the analyzed countries. The values of IER reflecting this problem are presented in Figure 6.

The IER for China has been falling faster than for the Triad, with σ-convergence taking place, as indicated by the downward-sloping trend line for this indicator. However, throughout the examined period, China attained the greatest IER values, demonstrating high returns on innovative activity in relation to expenditures incurred in this country. This leads to the interesting question about the reasons for the high efficiency of the Chinese innovation system.

4. Discussion

The analysis performed confirms the innovation performance convergence between China and the developed Triad economies: the EU, Japan, and the US. The data demonstrates fast improvement in the Summary Innovation Index of China in relation to the Triad economies, indicating a convergence process. The levels of the US and the EU innovation performance remain similar, with a slight lead of the American economy. The Chinese economy lags behind the Triad especially in innovation capability, measured by the input subindex, with relatively high results in innovation position, measured by the output subindex, and in the innovation efficiency ratio. This corresponds to the observation on the reliance of the Chinese innovation system on international technology transfer, for example through foreign direct investment (FDI). Lin et al. (2021) found that technology transfer results in considerably localized spillovers to surrounding enterprises, not just in the form of patents but also in higher productivity and revenue growth. This is fueled by so-called forced technology transfer (FTT) policies, which is a practice in which a domestic government requires foreign firms to disclose their technology in exchange for market access. As a result, for years, multinational corporations have traded their technological expertise for market share in China (Steinbock, 2018). Excessive disclosure of trade secrets to the state is often a precondition for gaining regulatory approvals, for example in the pharmaceutical or chemical industry (Prud'homme & von Zedtwitz, 2019). This made the US government complain that American high-tech companies are forced to reveal their technology and trade secrets and that foreign firms are not permitted to own a majority stake in joint ventures in many industries. In fact, FDI and forced technology transfer are at the heart of all of these grievances, not trade (Gros, 2019). Hence, Chen et al. (2020) posit that the current US-China trade war is about technical domination more than trade.

According to Kowalski (2020), the key to China's development success is its narrowing the innovation divide by absorbing current technologies (e.g., through foreign investments) and strengthening domestic capacity to use and progress on them (e.g. through political, financial and regulatory support of the central government for innovative enterprises, improving the quality of higher education and creation of high-tech clusters. This is important for China as economies with high innovation capability are characterized also by high absorptive capacity, which is regarded as a central moderating factor in the innovation process. The results of the research (Zeng et al., 2019) reveal that absorptive capacities facilitate innovation in China, especially in technologically advanced cities. The importance of absorptive capacity in China is confirmed by Howell (2020), as it assists this economy in transition towards an innovation-led growth model and technological upgrading.

Foreign direct investments contribute strongly to the development of high-tech industries, like pharmaceuticals, which were one of the first sectors in China to open up to foreign investors. Since 1980, when the first Sino-foreign pharmaceutical joint venture was founded, direct foreign investments have massively flown into China as a result of both spontaneous market dynamics and regional place-based preferential policies. However, there are considerable disparities in FDI localization across Chinese regions (Wang & Liu, 2019). Nonetheless, foreign investors have transferred new technologies driving China's indigenous pharmaceutical industries' modernization and expansion. They have brought sophisticated production lines, cutting-edge management skills and strategies, as well as more opportunities for information exchange and training. In terms of breadth and volume of manufacturing, China's pharmaceutical sector has expanded tremendously. Nonetheless, basic research has remained severely inadequate, and in comparison to the US, China's pharmaceutical sector is still highly underdeveloped (Wang et al., 2009).

The general trend is that the technology spillover benefits of FDI are greater in Chinese locations where FDI inflow is more concentrated spatially (Zhao et al., 2020), as demonstrated by the expanding high-technology clusters. This is related to the observation of the dynamic creation of clusters in China, particularly on the east coast, which goes together with serious escalations in regional discrepancies (Kowalski, 2022). However, while megacities such as Shanghai or Beijing have been in the center of attention as possible investment locations for a long time, China's increase in innovation performance and economic development is taking place in less known cities such as Dalian, Ningbo or Wuhan, which have emerged as significant settings of clusters in innovative sectors, such as biotechnology (Wang et al., 2015). In light of this, the Belt and Road Initiative (Cerulli et al., 2016), which aims to connect Asia and Europe, may play a special role in developing inland areas, including clusters along the Yangtze River's middle reaches, mostly around Chongqing and Chengdu agglomerations, which might play a key role in the expansion of western region (Kowalski, 2019). According to O'Connor and Gu (2014), the emergence of Chinese clusters in creative industries contribute to build the creative class and lead to the fusion of technology and culture.

The results of the study are in line with the findings of key global reports on innovation. According to Global innovation index 2021 (Dutta et al., 2021), since 2014, China has progressively climbed the Global Innovation Index (GII) rankings, establishing itself as a global innovation leader and closing in on the top ten each year. According to the report, China's performance is at the frontier of achievement, most notably in terms of innovation outputs. China's patents per capita are higher than those of Japan, Germany, and the United States, and even more outstanding in absolute terms. The same is true for trademarks and industrial designs by country of origin as a percentage of GDP. The GII 2021 report has also shown high resilience of China's innovation during the COVID-19 pandemic, often reaching new peaks concludes that investment in innovation had exceptional resilience during the COVID-19 epidemic, reaching new peaks in some areas, e.g. R&D expenditures and international patent filings. China also remains the only middle-income country among the top 30 most innovative economies in the world. According to OECD (2021), China, together with the United States, are the two main contributors to publications on PubMed in the area of COVID-19. Additionally, they intensified their collaboration in research subsequent to the outbreak (Fry et al., 2020). International scientific collaboration in the area of COVID-19 began with data and viral material being exchanged from China to foreign research centers. After the United States, China ranks second in vaccine clinical trials. This confirms that COVID-19 provided China the opportunity to develop its innovation capability and converge towards world innovation leaders.

There has been a recent surge in interest in the impact of culture on innovation. As it greatly contributes to business and economic development, this influence has been acknowledged as a crucial aspect in international management (Rohlfer & Zhang, 2016). Different studies highlight complicated and distinctive link between culture and creativity (Tian et al., 2018). It is recognized that the success of innovation in various technical fields varies between different countries in part due to differences in national cultures, which influence the norms and values that guide and constrain both people in communities and societies at large. The role of culture in innovation performance is especially interesting in the case of China because of its specific culture strongly influenced by Confucianism. Its innate conservatism, represented in the idea of the mean, may function as a cultural deterrent to breaking with tradition and innovating (Rowley & Oh, 2020). According to Abrami et al. (2014), China's innovation differs from the West, as it accentuates centralized approach. However, the tendency in China toward greater centralization of authority is considered as a barrier to innovation, given the level of interaction complexity required in an innovation system (Ahlstrom et al., 2018).

In recent decades, China's manufacturing industry has suffered from a lack of autonomous innovation capability and a poor resource utilization rate, resulting in a slew of pollution-related issues. It was intensified by China's remarkable economic growth, which has been significantly reliant on high consumption of energy, particularly fossil fuel energy (Ji & Zhang, 2019). Consequently, the central government has been concentrating on developing policies aiming to increase the level of investment in R&D in green innovation in recent years (Zhang et al., 2019). For instance, in the 13th Five-Year Plan (FYP), energy innovation and green development emerged as critical future principles (Song et al., 2017). Another example is the "Made in China 2025" strategy to improve the local manufacturing industry's innovation capabilities and achieve green and sustainable development. In this way, the technological progress in China impacts the economy and society by innovations in the area of energy efficiency and reduction in emissions, which enhance green total factor productivity (Li et al., 2020). It is further explored by Yang et al. (2021), who analyze the role of technical innovation in low-carbon economic development in China, with long-term consequences for international competitiveness. In this study, the authors indicate that there are about 130 central 690 local regulations to promote new-energy vehicles.

Conclusions

The research conducted confirms the convergence in innovation performance between China and more developed economies, such as the EU, Japan, and the US. The data reveals that China's innovativeness level has been rapidly improving in comparison to the Triad economies. To deepen the analysis, the innovativeness of the economy was decomposed into innovation capability, innovation position, and their relationship, which denotes the efficiency of the innovation system, indicating how effectively an economy converts innovation inputs into outputs. When calculating innovation capability, the input subindexes for the Triad are significantly higher than those for China. From a dynamic standpoint, however, we can see a pattern of σ-convergence for these economies, as indicated by the downward sloping trend line for the standard deviation. When analyzing the innovation position, China is achieving higher values of the output subindex. One possible explanation is that the Chinese economy is heavily reliant on external sources of innovation and that international technology transfer drives its innovation processes. However, there is a greater degree of σ-convergence in terms of innovation position among the countries studied, as evidenced by the coefficient of the trend line for the standard deviation. For the entire examined period, innovation efficiency, measured as the ratio of the output subindex to the input subindex, was consistently higher in China than in the EU, Japan, and the US. These, however, may reflect the comparatively low levels of innovation capacity in the Chinese economy. Similar to the process of convergence of innovation capacity and position, a process of convergence of innovation efficiency can be observed between the examined economies over the analyzed period. These research results support a more general thesis on the world's convergence in innovation performance in the global economy, which has been gradually losing a clear traditional distinction into innovation leaders (e.g. the EU, Japan, and the US) and innovation follower, i.e. China.

The above findings demonstrate some challenges faced by developed countries, which gradually losing their competitive advantages in high-tech sectors. The Triad copes with competitive pressure from China, which moving into higher-value-added areas of the global manufacturing industry. The study also has some implications for the EU countries, which are still not positioned among innovation leaders, such as those in Central and Eastern Europe (CEE). Chinese experiences demonstrate that narrowing the innovation divide through absorbing foreign technologies and developing indigenous abilities to utilize them is critical to convergence processes.

The study is not without limitations. First of all, it focuses on the macroeconomic perspective, and therefore the analysis is based on aggregated indicators, but in such an approach, the innovation trends in particular scientific and technological fields are overlooked. Moreover, the study concentrates on only one developing country – China, so it does not provide enough evidence to generalize the finding on the convergence between developed and developing countries. This provides directions for further research, which may extend its scope beyond China and investigate the convergence of selected developing economies (e.g., BRICS) versus selected developed economies. It will be also important to study future developments in the world geography of innovation, especially concerning the consequences of the Russia-Ukraine war and COVID-19 pandemic, as well as related economic crises on the innovation performance of developed and developing countries, and its influence on the innovation divide in the global economy.

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