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MEASURING THE TECHNOLOGICAL COMPETITIVENESS OF ECONOMIES WITH THE PTCE METHOD: PRC VS. USA 2000–2020

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Abstract. The relationship between China (PRC) and the United States (USA) has reached an unprecedented level of tension, mainly due to economic and technological rivalry. This study introduces an original quantitative method, the Pentagon of Technological Competitiveness of Economy (PTCE) to measure the technological competitiveness of both countries from 2000 to 2020. The findings reveal that while the USA remains a global technological leader, the PRC is emerging as a formidable challenger. Although the USA still holds the lead, signs of decline are visible, while the PRC exhibits a remarkable upward trajectory in technological competitiveness. The findings provide actionable recommendations for policymakers. To reinforce its position as the unrivaled technological leader, the USA should prioritize enhancing capabilities in areas such as patents, scientific articles and the export of high technology and STEM-related products. For the PRC there is an unprecedented opportunity to surpass the USA in technological leadership by strategic investments in research, innovation and human capital development. The novelty of this research lies in two main areas: (i) its significant contribution to competitiveness analysis through the introduction of the PTCE method and (ii) its provision of a comprehensive assessment of the shifting technological dynamics between the USA and the PRC.

Keywords: competitiveness of economy, technology-based economies, public management, USA, PRC, comparative advantage, technological landscape, PTCE, innovation, human capital development

JEL Classification: C43, D81, O32, O34, O57, P11.

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1. Introduction

During past two decades the economic rivalry between People's Republic of China [PRC] and the global leader, the United States of America [USA], has made PRC the main title contender. The recently signed Regional Comprehensive Economic Partnership [RCEP] has the potential to strengthen this trend further (Ficek & Gawlik, 2022).

The aim of this article is to search for the reasons of this close-up in the differences between the technological competitiveness of USA's and PRC's economies. The main research questions are the following: (i) which of the two countries has the dominant position in the technological competitiveness of its economy? (ii) is this relation stable? (iii) can existing methods of PTCE measurement be improved?

The research design was based on mixed methodological approach, consisting of quantitative analysis of existing data sets, followed by a qualitative exploratory interpretation of obtained quantitative results. Data came from UIS Stat (UNESCO Institute for Statistics, 2022), UNCTAD (2022), WIPO (2022) and WoS statistics (Clarivate *Web of Science*, 2022). The study covers a two-decade time period (2000–2020). We used our own original research method proposal, the Pentagon of Technological Competitiveness of Economy [PTCE], which constitutes the main novelty of our article and its contribution to the development of Economics.

The article is composed of four chapters: (i) literature review; (ii) research design, methodology and methods; (iii) results; (iv) discussion, all followed by conclusions.

2. Literature review

In past five years, the Web of Science [WOS] database search returns 8278 articles for the search query (Topic = "competitiveness" AND Topic = "economy") (Clarivate *Web of Science*, 2023). Moreover, numerous authors signal the actuality and validity of this topic (Czarny & Żmuda, 2018; Liu, 2017; Molendowski, 2021; Radman & Belin, 2017). Żmuda (2017) traces the popularization of the concept of international competitiveness of the economy back to the 1985 Reagan's Presidential Commission on Industrial Competitiveness. Flejterski and Majchrzak (2018) observe that the competitiveness of economies is mentioned also in institutional approaches and policies, e.g. the Organization for Economic Co-operation and Development [OECD], the European Commission [EC], the World Economic Forum [WEF] or the International Institute for Management Development [IMD]. Although Flejterski and Majchrzak (2018) found more than 400 different definitions of competitiveness in scientific literature, none of them became predominant. Table 1 presents selected definitions and interpretations of the competitiveness of economy, a term often equivalent in scientific literature to economic competitiveness (Shvindina, 2020).

In his criticism of the competitiveness of the economy concept, which at first has been perceived as "non-scientific, a political folly" (Peneder, 2016, p. 6), Krugman (1994) observes that the term is misunderstood by those who use it as it refers to enterprises only. He also argues that an uncompetitive enterprise will fail, while an uncompetitive economy will not collapse and that competitive economies with low foreign trade ratios is just a "funny" term for productivity. On the other hand, competitiveness is by some considered economy's growth factor rather than its condition of existence as in (Trishch et al., 2023)

Most researchers quoted in Table 1 agree on the competitiveness meaning an ability of a country to improve welfare, development, economic growth and living standards. They differ on tools which provide such enhancements, though.

Already Yglesias (2003) observed that the main source of raise in competitiveness comes from the ability of countries to create, assimilate and export technologies. He is backed by Alvarez-Aros and Bernal-Torres who state that "competitiveness has evolved throughout history, from a static and dependent concept to another where it competes productively and with comparative and positioning advantages, until it reaches a dynamic, integrative, complex, multidimensional and systemic concept that also contemplates the capacity of people and that requires a human and technological balance in organizations" (2021, p. 1).

Table 1. Selected definitions of the competitiveness of economy (source: authors' own elaboration based on literature review)

Author	Definition of competitiveness of economy
IMD (2022)	An economy's competitiveness cannot be reduced only to GDP and productivity because enterprises also have to cope with political, social and cultural dimensions.
Novoskoltseva et al. (2021, pp. 101–102)	Based on GDP indicators, productivity (dependent changes) and digitalization factors, which mainly reflect the quality of human capital and its compliance with the needs of the digital economy.
Molendowski (2021, p. 87)	A long-term phenomenon, with structural characteristics, […] that distinguishes economic competitiveness from business or sectoral competitiveness, representing efficiency-related categories.
Boikova et al. (2021, p. 1)	Main precondition of the national economies in increasing GDP per capita and well-being, i.e., better conditions for health, social protection and living standards.
Krstić et al. (2020, p. 2)	Quality higher education and training are conditions for ensuring the efficiency of the economy, so the improvement of education at the tertiary level would enable an easier transition of the economy to a higher level of development.
Cheba et al. (2020, p. 1401)	In the long-run, not only economic but also human development and ecological sustainability are important ingredients for high productivity and a prosperous society.
Schwab (2019, p. 2)	The attributes and qualities of an economy that allow for a more efficient use of factors of production.
Peña-Vinces et al. (2019, p. 302)	Sustained economic growth, export upgrading and employment growth.
Kiseľáková et al. (2019, p. 442)	The issue of insufficient innovation development and inappropriate corruption perception is considered to be key determinants influencing the assessment of the global competitiveness.
Czarny and Żmuda (2018, p. 122)	Ability of an economy to adjust exports structures to the changes in the global technology.
Radman and Belin (2017, p. 50)	The level of productivity defines the level of prosperity that can be earned by an economy. […] Economies that are more competitive are able to produce higher levels of income for their citizens.
Liu (2017, p. 116)	Associated with high living standards and locational attributes which drive growth and prosperity over the long term.
Żmuda (2017, p. 108)	National ability to grow / develop sustainably.
Peneder (2016, p. 10)	The ability of an economic system to develop.
OECD (2001)	Competitiveness is a measure of a country's advantage or disadvantage in selling its products in international markets.

Table 1 reveals another common method of increasing national competitiveness: raising productivity. I.e., Boggio and Barbieri (2016) mention, that a country with high competitiveness will have a high rate of productivity. This brings us to a recent, less researched concept of international technological competitiveness of economy [TCE] which is closely connected to productivity. Already Posner (1961) saw the source of country's competitiveness in its technological potential. It is also the funding principle of the fourth industrial revolution, where the accumulation of high-tech and knowledge plays a key role in the international distribution of wealth (Schwab, 2016). Kołodko (2020a) writes that the main fields of competitiveness between knowledge-based economies are human capital and technology, which we can define as the technological competitiveness of a national economy. Ghazinoory and Ghazinouri (2009) define the knowledge-based economy as a composition of science and technology capabilities. They also agree that technology plays a crucial role in such economies because of its impact on criteria connected with efficiency and effectiveness. They also point out that the modern globalized World highly relies on knowledge, a scarce factor in the developing countries – backed by Uskokovic et al. (2010) who state that the most competitive countries are knowledge- and technology- intensive. Krstić et al. (2020) add the level of education as another determinant of country's competitiveness.

After consideration, we decided to define the competitiveness of the economy as a measure of international standing of countries' economies that largely depend on productivity which is a function of technological capabilities of the discussed economy.

Wosiek (2019) defines technological competitiveness as the long-term ability to create internal economic conditions conducive to a rapid adaptation of new knowledge and existing technologies to strengthen its own technological potential. One can easily observe the similarity with the definition of competitiveness sensu stricto. Rutkauskas (2008) defines it as a technological and organizational perfection of the fields of activity, and counts as one of three main attributes of overall country's competitiveness.

Most researchers quoted above place the base of competitiveness in productivity, with its main factors being the technological potential and innovation. Peña-Vinces et al. (2019) note that scientific capabilities (number of researchers and patents, scientific production, research and development budget) of an economy have significant impact on its manufacturing sector, which leads to a grow of a productivity in an economy. Also Uskokovic et al. (2010) consider scientific research as the reason of long-term prosperity and productivity.

Another determinant of TCE could be the ICT capabilities, but Novoskoltseva et al. (2021) proved that it cannot be used as an indicator of country's economic competitiveness. Also Barba-Sánchez et al. (2018) found that the indisputable impact of ICT on the competitiveness of companies cannot be directly transferred to the macroeconomic level. On the other hand, Ivana et al. (2018) consider ICT as key component of knowledge-based digital economies with strong pro-competitive potential. This statement is backed by Sergushina et al. (2021) who consider an effective use of digital technologies as a base of improving competitiveness both at micro- and macro-scale. As the impact of ICT capabilities on the TCE remains debatable due to a lack of enough empirical proofs, we decided to omit this component, as in (Chistov et al., 2020).

Boikova et al., (2021) propose another factor of TCE: the technological level of exported goods. The comparative advantage theory states clearly that technologically advanced countries tend to export more technologically advanced goods. Fang et al. (2022) add to the high-tech product exports the number of copyrighted patents. Grupp (1995) pointed at the need to recognize technology as a major and separate category of national competitiveness. He also observed that most patent rights were generated by private and corporate research, rather than via academic publications.

Another proof of importance of the technological aspect of competitiveness comes from the theory of foreign trade where it is the technological gap which is perceived as an important incentive to international trade. Liu (2017) follows this reasoning by praising the technological potential of the country as the main factor shaping the dynamics of its exports and stating that the current perspective on the competitiveness of economies has been a result of the rapid development of technology in recent years. Radman and Belin (2017) came to similar conclusions.

Presented definitions of TCE can be unified as an economy's capabilities in such determinants of competitiveness as science, research & development and export of high-technology goods.

The presented literature review revealed an important number of research papers perceiving TCE being an important foundation of overall economic competitiveness, which, moreover, rapidly strengthens its importance. This requires the sophistication of existing research apparatus or new method proposals. We attempted to fill in this identified research gap by proposing our own Pentagon of Technological Competitiveness of Economy (PTCE).

The Main Research Thesis of our research states the following:

- MRT: USA still holds a dominant position in the technological competitiveness of economy, but is challenged by the PRC.

Three sub-theses will be verified as well:

- ST1: Between years 2000 and 2020 the USA were able to maintain a higher level of technological competitiveness of economy than the PRC.
- ST2: Since year 2000 the technological competitiveness of PRC has kept on progressing.
- ST3: Since year 2000 the distance in the technological competitiveness of the economy between PRC and USA has been diminishing.

3. Methodology and methods

We adopted a mixed methodological approach, combining a quantitative analysis of existing data sets with use of our own method proposal, the PTCE, for calculating and visualizing the competitive distance between the economies of PRC and USA.

Piontek (2000) discusses the usefulness of graphical visualization of economic models for their analysis, where she refers to Markowski's work on pentagonal reciprocity of competitive aims (Markowski, 1989) and Kołodko's proposal of the Pentagon of macroeconomic stabilization (1993). Schwab (2018) reminds that the polygonal form of presentation of synthetic data is also used by WEF in its Global Competitiveness Ranking, though with use of dodecagon. Brooks and Wohlforth (2015) proposed a diamond-shaped measure of technological output, with science and engineering articles and patents data as indicators.

We employed five indicators built around the revealed comparative advantage index (Stellian & Danna-Buitrago, 2022): RCA **(Revealed Comparative Advantage)**, RECA **(Researchers Comparative Advantage)**, RDCA **(Research & Development Comparative Advantage)**, RSCA **(Revealed Scientific Comparative Advantage)** and RTCA **(Revealed Technological Comparative Advantage)**. Their grouping into five triangles sharing the same top results in a pentagonal shape, as in (Kołodko, 1993):

- Triangle a, the Research and Development Activity Triangle (RDAT), links the RTCA and RDCA, as in Bolívar-Ramos (2017).
- Triangle b, the Research and Development Capabilities Triangle (RDCT), combines the RDCA and RECA (our own proposal).
- Triangle c is a combination of RECA and RSCA, as in the Scientific and Technical Human Capital Triangle (STHCT). It is aggregated value of the total STHC, cited by Ballesteros-Rodríguez et al. (2022), within a national economy.
- Inspired by Li et al. (2023), we combined RSCA and RCA into triangle d, the Knowledge-Based Export Competitiveness Triangle (KBECT).
- Although the relation between patenting and exports has not been fully explored yet, Moussa and Varsakelis (2022) prove the existence of such a causality. Rather one-sided, though, with patents providing basis for high-tech exports, rather than the opposite (Dereli, 2019). For this reason we proposed triangle e, the Technology-Based Export Competitiveness Triangle (TBECT), which is a combination of RCA and RTCA.

The choice of the studied period 2000–2020 was dictated by the need of observing long-term trends to lower the risk of obscuring the findings by the occurrence of demand-supply shocks or economic crises. Also the changes in technological ability alone, even if sometimes quick, do not necessarily translate into an equally rapid switch of competitive position. Moreover, most of the data was available until year 2020.

We employed existing data sets provided by UIS Stat, UNCTADSTAT, WIPO and WoS. The source selection criteria were: credibility, reliability, independence, availability of data for the period of study and availability of both PRC and USA data. Additionally, we shared Kołodko's (2020b) concern on the accuracy of official Chinese datasets, therefore we skipped data from Chinese governmental institutions.

Table 2. Sources of indicators used in PTCE (source: authors' own elaboration)

Indicator	Source	Calculated as…
RCA	UNCTADSTAT	… value of exports of high-tech products (LALL classification)
RECA	UIS Stat	… researchers per million inhabitants
RDCA	UIS Stat	… the R&D expenditures to GDP
RSCA	Web of Science	… the number of STEM-related scientific articles[a]
RTCA	WIPO	… the number of STEM-related patents applications[b]

Note: [a] STEM-related 21 categories (out of 152): engineering; physics; materials science; science technology other topics; biochemistry, molecular biology; mathematics; metallurgy, metallurgical engineering; energy, fuels; computer science; pharmacology, pharmacy; food science technology; neurosciences, neurology; optics; telecommunications; biotechnology, applied microbiology; mining, mineral processing; construction building technology; electrochemistry; automation control systems, robotics; and medical laboratory technology;
[b] STEM-related 22 categories (out of 35): electrical machinery, apparatus, energy; audio-visual technology; telecommunications; digital communication; computer technology; semiconductors; optics; analysis of biological materials; medical technology; biotechnology; pharmaceuticals; macromolecular chemistry, polymers; materials, metallurgy; surface technology, coating; micro-structural and nanotechnology; chemical engineering; machine tools; engines, pumps, turbines; other special machines; thermal processes and apparatus; mechanical elements; civil engineering.

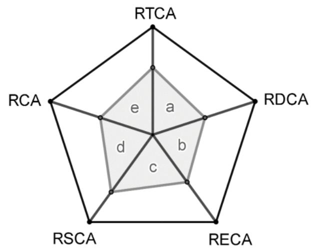

Figure 1. Pentagon of Technological Competitiveness of Economy (PTCE) (source: authors' own elaboration based on literature review)

For RSCA and RTCA we followed Roberts & Wolf's (2018) advice to concentrate on industries and fields of study related to STEM (Science, Technology, Engineering, and Mathematics). The U.S. Bureau of Labor Statistics recognizes them as directly linked with high-tech industries.

Figure 1 represents the PTCE model.

Equations (1)–(5) below show the mathematical construction of employed indicators.

$$RTCA^{a} = \frac{P_{ij}}{\sum iP_{ij}} : \frac{\sum jP_{ij}}{\sum i \sum jP_{ij}}; \tag{1}$$

$$RSCA^{b} = \frac{S_{ij}}{\sum iS_{ij}} : \frac{\sum jS_{ij}}{\sum i \sum jS_{ij}}; \tag{2}$$

$$RECA^{c} = \frac{R_{ij}}{\sum iR_{ij}} : \frac{\sum jR_{ij}}{\sum i \sum jR_{ij}}; \tag{3}$$

$$RDCA = \frac{D_{ij}}{\sum iGDP_{i}} : \frac{\sum jD_{ij}}{\sum i \sum jGDP_{ij}}; \tag{4}$$

$$RCA = \frac{X_{ij}}{\sum iX_{ij}} : \frac{\sum jX_{ij}}{\sum i \sum jX_{ij}}, \tag{5}$$

where:

P_{ij} – patent applications in country i in technology j;

ΣiP_{ij} – all patent applications in technology j;

ΣjP_{ij} – all patent applications in country i;

$\Sigma i\Sigma jP_{ij}$ – all patent applications in the World;

S_{ij} – the number of scientific papers published in country i in reaserch area j;

ΣiS_{ij} – total number of scientific papers published in research area j;

ΣjS_{ij} – total number of scientific papers from country i;

$\Sigma i\Sigma jS_{ij}$ – total number of scientific papers from all countries;

$\frac{R_{ij}}{\sum iR_{ij}}$ – Researchers (in full-time equivalent per milion inhabitants) in country i;

$\frac{\sum jR_{ij}}{\sum i \sum jR_{ij}}$ – Researchers (in full-time equivalent per milion inhabitants) in every contry;

$\frac{D_{ij}}{GDP_i}$ – Research and development expenditure as a proportion of GDP in country *i*;

$\frac{\sum jD_{ij}}{\sum i \sum jGDP_{ij}}$ – Research and development expenditure as a proportion of GDP in every country;

X_{ij} – value of exported products from country *i* in *j* branch;

ΣiX_{ij} – total value of World exported products from *j* branch;

ΣjX_{ij} – total value of country *i* exported products;

$\Sigma i\Sigma jX_{ij}$ – total value of World exported products.

Equations (6)–(7) represent the mathematical notation of the proposed PTCE model.

$$PTCE = [(RTCA*RDCA) + (RDCA*RECA) + (RECA*RSCA) + (RSCA*RCA) + (RCA*RTCA)]*k; \quad (6)$$

$$k = \frac{1}{2}\sin 72^\circ \approx 0.476, \quad (7)$$

where:

PTCE – Pentagon of Technological Competitiveness of Economy;
RTCA – Revealed Technological Comparative Advantage;
RSCA – Revealed Scientific Comparative Advantage;
RECA – Revealed Researchers Comparative Advantage;
RDCA – Revealed Research and Development Comparative Advantage;
RCA – Revealed Comparative Advantage;
k – mathematical formula for the area of the triangle.

As the value of RECA for the USA significantly exceeds values of other indicators, a need for normalization arises. Equations (8)–(11) show resulting features of PTCE's components.

$$aPTCE \in [0,1]; \quad (8)$$

$$aT \in [0,0.2]; \quad (9)$$

$$rT \geq 0.008; \quad (10)$$

$$rPTCE \geq 0.04, \quad (11)$$

where:

aPTCE – total PTCE area;
aT – singular triangle area;
rT – achieved revealed comparative advantage of a singular triangle area (using a 0–5 indicator scale);
rPTCE – achieved revealed comparative advantage of total PTCE area (using a 0–5 indicator scale).

To allow the comparability of the PTCE model, its total area was normalized to 1, which limits the maximum area of one particular triangle to 0.2. Thus, with the adopted 0–5 indicator scale, each indicator has to be multiplied by l = 0.13 – a value derived from Eq. (12):

$$l = \frac{0.649}{n}, \quad (12)$$

where: *n* – maximum indicator scale chosen.

For the chosen a maximum scale for each indicator of 5, our l = 0.13.

The following chapter reveals the results of the application of our PTCE model with calculations based on real and actual data from the sources described above.

4. Results

This chapter presents the results of PTCE model application in two forms: numerical (Tables 3–4) and graphical (Figures 2–8). To assure the comparability of results, we employed linear and logarythmic scales.

Table 3 shows values of calculated PCTE indicators for PRC and USA in years 2000–2020.

Table 3 proves that since 2016 the PRC has achieved a revealed comparative advantage in every indicator, which confirms ST2. Nonetheless, the best performing indicator was the USA's RECA, with PRC's RCA coming second in years 2005–2014. For the rest of the studied period, it was the USA's RDCA ranking second highest. Paralelly, the USA kept the dominant position in RECA, sometimes RDCA and RCA (until 2013, when overtaken by PRC). Therefore

Table 3. PTCE indicators for PRC and USA in years 2000–2020 (source: authors' own computations based on data from Table 2)

Year	PRC					USA				
	RSCA	RTCA	RECA	RDCA	RCA	RSCA	RTCA	RECA	RDCA	RCA
2000	1.32	1.10	0.67	0.59	0.99	0.92	1.00	4.36	1.74	1.47
2001	1.32	1.02	0.70	0.61	1.09	0.91	0.98	4.35	1.73	1.47
2002	1.30	1.00	0.75	0.70	1.24	0.91	0.98	4.39	1.68	1.42
2003	1.29	1.00	0.76	0.74	1.43	0.90s	0.98	4.52	1.69	1.43
2004	1.27	0.98	0.80	0.81	1.58	0.90	0.99	4.34	1.67	1.23
2005	1.35	0.98	0.93	0.86	1.69	0.91	0.99	4.12	1.66	1.21
2006	1.35	0.97	0.98	0.89	1.68	0.89	1.00	4.09	1.66	1.42
2007	1.37	0.97	1.10	0.89	1.75	0.91	0.99	3.94	1.70	1.39
2008	1.41	0.97	1.19	0.91	1.81	0.90	0.99	3.99	1.74	1.38
2009	1.40	1.00	0.84	1.02	1.74	0.89	0.98	4.05	1.72	1.08
2010	1.44	1.01	0.87	1.06	1.80	0.90	0.97	3.80	1.70	1.04
2011	1.43	1.00	0.91	1.09	1.88	0.90	0.98	3.81	1.70	1.05
2012	1.44	1.03	0.94	1.17	1.86	0.90	0.97	3.69	1.64	1.02
2013	1.43	1.04	0.96	1.20	1.87	0.89	0.97	3.69	1.63	0.98
2014	1.43	1.05	0.96	1.20	1.73	0.87	0.96	3.71	1.62	0.96
2015	1.41	1.05	0.99	1.22	1.59	0.87	0.96	3.68	1.65	0.93
2016	1.40	1.04	1.01	1.24	1.56	0.87	0.95	3.59	1.67	0.93
2017	1.41	1.05	1.01	1.23	1.60	0.85	0.94	3.63	1.68	0.88
2018	1.41	1.03	1.03	1.22	1.64	0.84	0.94	3.75	1.71	0.86
2019	1.40	1.03	1.12	1.24	1.58	0.82	0.93	3.66	1.75	0.86
2020	1.37	1.01	1.18	1.24	1.47	0.81	0.93	3.96a	1.79	0.85

Note: [a] Due to the lack of available data on the number of employees in R&D, we replaced this data with the arithmetic average of the rest of the years.

we can state that in years 2000–2020 the PRC's indicators of comparative advantage proved to be more stable, sustainable and growing – which confirms ST3.

Table 4 shows the values for total PTCE area and areas of singular triangles for PRC and USA in years 2000–2020.

Table 4. PTCE components for PRC and USA in years 2000–2020 (source: authors' own computations using data from Table 2)

Year	PRC						USA					
	PTCE	RDAT	RDCT	STHCT	KBECT	TBECT	PTCE	RDAT	RDCT	STHCT	KBECT	TBECT
2000	0.035	0.005	0.003	0.007	0.010	0.009	0.130	0.014	0.061	0.032	0.011	0.012
2001	0.036	0.005	0.003	0.007	0.012	0.009	0.128	0.014	0.060	0.032	0.011	0.012
2002	0.040	0.006	0.004	0.008	0.013	0.010	0.126	0.013	0.059	0.032	0.010	0.011
2003	0.045	0.006	0.005	0.008	0.015	0.012	0.129	0.013	0.061	0.033	0.010	0.011
2004	0.048	0.006	0.005	0.008	0.016	0.012	0.121	0.013	0.058	0.031	0.009	0.010
2005	0.055	0.007	0.006	0.010	0.018	0.013	0.116	0.013	0.055	0.030	0.009	0.010
2006	0.056	0.007	0.007	0.011	0.018	0.013	0.119	0.013	0.054	0.029	0.010	0.011
2007	0.060	0.007	0.008	0.012	0.019	0.014	0.117	0.014	0.054	0.029	0.010	0.011
2008	0.064	0.007	0.009	0.014	0.021	0.014	0.119	0.014	0.056	0.029	0.010	0.011
2009	0.058	0.008	0.007	0.009	0.020	0.014	0.114	0.013	0.056	0.029	0.008	0.008
2010	0.061	0.009	0.007	0.010	0.021	0.015	0.108	0.013	0.052	0.027	0.008	0.008
2011	0.064	0.009	0.008	0.010	0.022	0.015	0.109	0.013	0.052	0.028	0.008	0.008
2012	0.066	0.010	0.009	0.011	0.021	0.015	0.103	0.013	0.048	0.027	0.007	0.008
2013	0.068	0.010	0.009	0.011	0.022	0.016	0.102	0.013	0.048	0.026	0.007	0.008
2014	0.065	0.010	0.009	0.011	0.020	0.015	0.101	0.012	0.048	0.026	0.007	0.007
2015	0.062	0.010	0.010	0.011	0.018	0.013	0.101	0.013	0.049	0.026	0.007	0.007
2016	0.062	0.010	0.010	0.011	0.017	0.013	0.099	0.013	0.048	0.025	0.006	0.007
2017	0.063	0.010	0.010	0.011	0.018	0.013	0.099	0.013	0.049	0.025	0.006	0.007
2018	0.064	0.010	0.010	0.012	0.019	0.014	0.102	0.013	0.052	0.025	0.006	0.006
2019	0.065	0.010	0.011	0.013	0.018	0.013	0.101	0.013	0.051	0.024	0.006	0.006
2020	0.063	0.010	0.012	0.013	0.016	0.012	0.108	0.013	0.057	0.026	0.006	0.006

Table 4 reveals more PTCE triangles with revealed comparative advantage for the PRC, however, surprisingly, it still did not allow the PRC to overtake the USA in the overall PTCE score, which confirms ST1.

In year 2000 USA had comparative advantage in all PTCE triangles, with PRC scoring lowest, but still having comparative advantage (0.011) in KBECT. By 2020 the PRC had revealed comparative advantage in every triangle, while USA only in three of them. The crucial moment for PRC came in 2011, when it achieved a revealed comparative advantage in all of the triangles.

It is worth noting that USA lost its revealed comparative advantage in TBECT already in 2014 and in KBECT in 2012 – in the studied period these were also the highest scoring triangles for PRC.

In 2004, the PRC achieved an overall revealed comparative advantage, while USA did not. This was due to a huge PRC KBECT score this year. Nevertheless, throughout the studied period USA kept a higher overall PTCE score. Even in 2013, where PRC's score was the highest, USA's lowest PTCE from 2017 was still higher.

Figures 2–8 show graphical representations of the PTCE and its components in the studied period.

Figure 2 uses a linear scale to picture the PTCE of PRC in the studied period.

Figure 2 clearly shows, that PRC's technological competitiveness had seen a the most rapid growth between year 2000 and 2005. Moreover, it appears that throughout the studied period it kept a sustainable growth among all the indicators.

Figure 3 uses a linear scale to picture the PTCE of USA in the studied period.

Figures 4 and 5 use a logarithmic scale to graphically compare the PTCE of PRC and USA in 5-year time spans. The logarithmic scale increases the readability, as the dominance of RECA indicator for the USA obscures the comparison – as pictured on Figure 3.

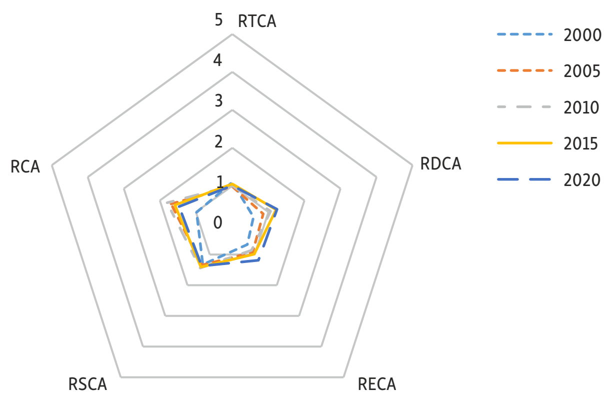

Figure 2. PTCE of PRC in years 2000, 2005, 2010, 2015, 2020 (linear scale) (source: authors' own computations using data from Table 2)

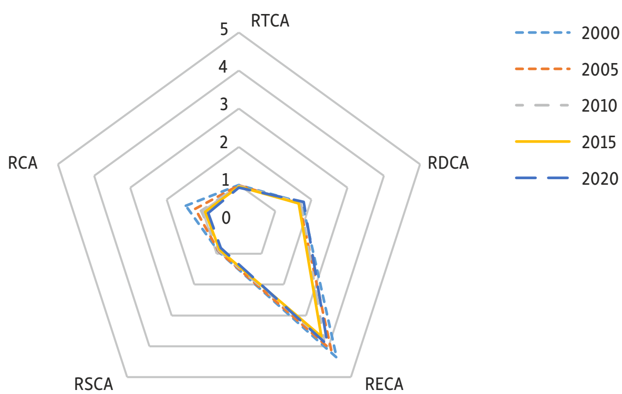

Figure 3. PTCE of USA in years 2000, 2005, 2010, 2015, 2020 (linear scale) (source: authors' own computations using data from Table 2)

Figure 4 shows the dynamics of PTCE values for PRC and USA in the studied period.

Figure 4 shows that both economies didn't change drastically their PTCE structure throughout the studied period. However, PRC had the most dynamic growth between year 2000 and 2005.

Figure 5 shows the same dynamics as Figure 4, but PRC and USA are juxtaposed on the same graph – for an easier graphical comparison.

Figure 5 implies that the USA has been keeping a significant advantage in RECA and RDCA, which points at the RDCT and STHCT (less) being main sources of revealed comparative advantage for this country. However, the USA's KBECT was superior to the PRC's only in year 2000.

In most of the studied period, the PRC had comparative advantage in RDAT, KBECT and TBECT, but at a too small margin to overtake their competitor in the total PTCE. Nevertheless,

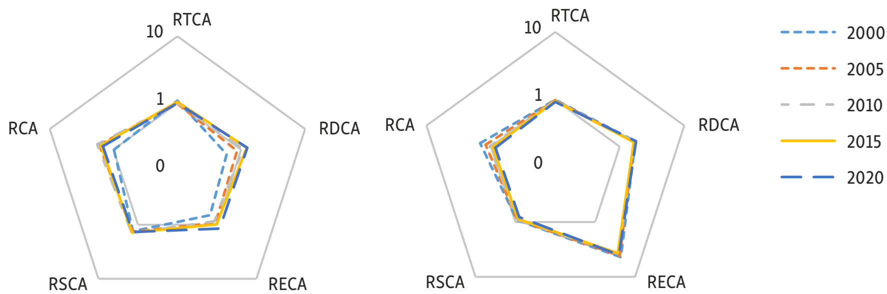

Figure 4. PTCE of PRC (left) & USA (right) in years 2000, 2005, 2010, 2015, 2020 (logarithmic scale) (source: authors' own computations using data from Table 2)

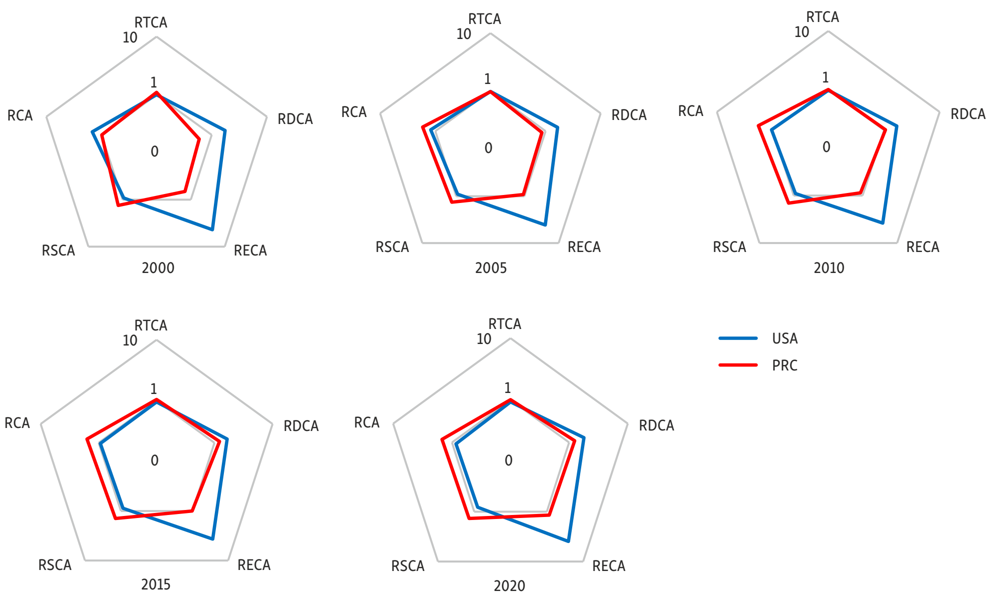

Figure 5. PTCE of PRC Vs USA in years 2000, 2005, 2010, 2015, 2020 (logarithmic scale) (source: authors' own computations using data from Table 2)

the constantly upward trend of PRC's indicators contrasts with the falling indicator development dynamics of the USA.

Interestingly, the PRC's PTCE components displayed symmetry – their singular triagle areas were almost equal throught the entire studied period. Opposingly, the PTCE of USA was mostly dependent on RDCT and STHCT, which in turn owed their importance to only one indicator, the RECA. These interdependencies are presented on linear scale Figures 6–8 below.

Figure 6 shows the importance of PTCE components for the total PTCE of PRC in the studied period.

Having pointed out that PRC kept their growth in technological competitiveness in a stable and sustainable way, Figure 6 only confirms it. There seem to be no dominant triangle in the structure of PRC' PTCE.

Figure 7 shows the importance of PTCE components for the total PTCE of USA in the studied period.

Figure 7 seem to prove that most of USA technological competitiveness is based on the RDCT. However, RDCT is mostly dependent on the values of RECA index.

Figure 8 summarizes our results by providing a comparison of the total PTCE of PRC and USA in years 2000–2020.

As it can be clearly seen, PRC couldn't overtake US' economy within technological competitveness. This confirms our main research thesis which states that USA still holds a dominant position in this field. Moreover, there is a strong upward trend for PRC's economy, which makes us agree on the fact that the USA position is challenged. This also proves our first subthesis. The second subthesis should be taken as non conclusive because there were times when PRC technological competitiveness went down. However, the trend is clearly upward. Last, third subthesis stating that the distance between USA and PRC in terms of technological competitiveness kept diminishing can be confirmed.

The following section contains a discussion of the above outcomes of the application of our PTCE model.

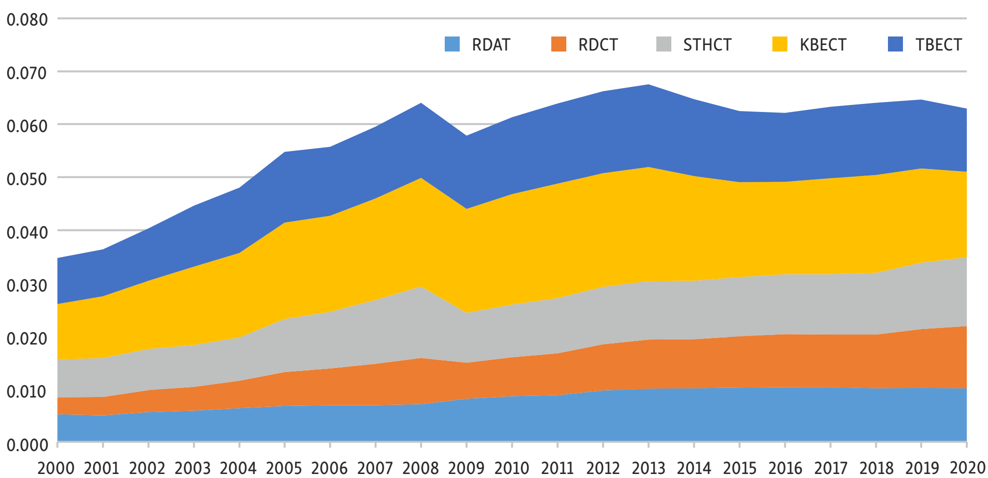

Figure 6. PTCE components of PRC in years 2000–2020 (linear scale)
(source: authors' own computations using data from Table 2)

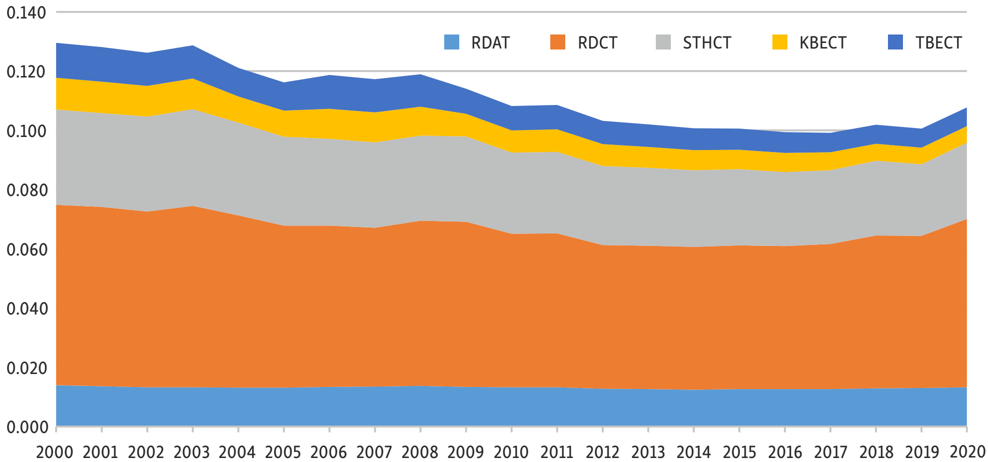

Figure 7. PTCE components of USA in years 2000–2020 (linear scale)
(source: authors' own computations using data from Table 2)

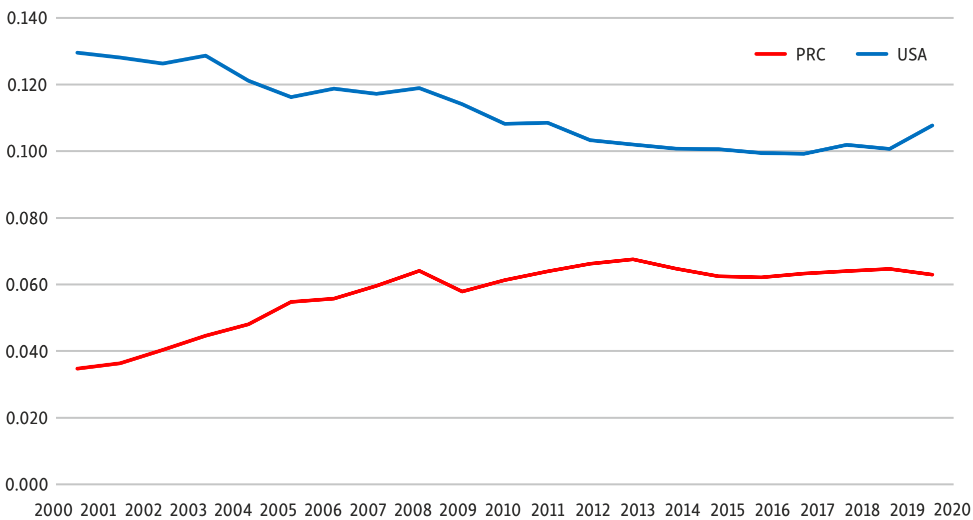

Figure 8. PTCE of PRC and USA in years 2000–2020 (linear scale)
(source: authors' own computations using data from Table 2)

5. Discussion

PRC competitiveness development in a 2000–2020 years may be an effect of PRC's geo-economic strategy (Pu, 2018), which is, as described by Blackwill and Harris (2016) as usage of economic instruments for geopolitical goals. What is more, as showed by Pu (2018), PRC doesn't seek global leadership rapidly. It rather tends to walk the path of so-called "peaceful development". Furthermore, this author argues that "PRC will not abandon its developing country status anytime soon", even though PRC may be seen as a potential global leader (Pu, 2018, p. 56).

Most recent research papers discussing the economic competition between PRC and USA focus on the recent trade war (a term forbidden in PRC). Moreover, the literature review on recent research on the competitiveness of economies, *strico senso*, perceive the technological competitiveness only as one of its many components. There is very little research focusing on the technology as the main driver of economic competitiveness regarding those two countries – a trend opposite to Europe where such a perspective can be found in works of Cheba et al. (2020), Flejterski and Majchrzak (2018), Grupp (1995), Kiseľáková et al. (2019), Novoskoltseva et al. (2021), Wosiek (2019).

The closest approach to the one proposed in this paper can be found in Li et al. (2023). Their study confirms our results, however their KBES model did not take into consideration the high-tech exports which are one of the indicators of our PTCE model.

Huang and Sharif (2015) state that the competitiveness of the economy is a result of national intellectual capital. In their study the USA held a strong leading position among World's largest countries almost throughout the studied period. Moreover, its trend was mostly upward. On the other hand, PRC also had a upward trend, but couldn't reach the level of USA, nevertheless the difference between these two economies decreased. Zamora-Torres (2014) study, which used factorial analysis with indicators to some extent similar to PTCE, proved that USA is the leading country in Innovation and Technology Competitiveness, while PRC holds the second place.

Vo and Tran (2022a) do not share our concern on PRC becoming a global leader in the field of technology leader – with use of their own Index of National Intellectual Capital proposed in their other article (Vo & Tran, 2022b), similarly to Pu (2018) whose study proves that PRC's technological power is relatively much lower than the USA's one. In an innovation matter Cheng et al. (2023) indicated that PRC increased their strategic innovation lacking substantive innovation. Similarly to our subject, study conducted by Chen et al. (2023) using Digital economic index proved that PRC's level of it kept rising from 2012 to 2018. Other research made by Basu et al. (2018) concerned PRC's science and technology leadership potential. The study proved, that in many indicators, including gross expenditure on R&D, full-time equivalent researchers, PCT patent applications, scientific papers as relation to R&D investment PRC is already in lead, and in others, it will soon be a leader. Nonetheless, authors concluded that PRC is not yet a leader in science and technology.

The yearly competitiveness rankings published by WEF (2004–2020) and the 2000–2020 ranking by IMD (2022) confirm our results. Both reports point at differences between the two economies, but also underline their blurring on a year-to-year basis. In National Science Board's [NSB] Science and Engineering Indicators report for year 2000 the PRC was presented as a high-tech producer and exporter (NSB, 2000), which is contradictory to our findings for this year. NSB (2010) keeps the USA at the global top in knowledge and technology, which collides with our findings that already in 2010 the PRC had a way better competitive position towards the USA in terms of high technology exports. This discrepancy can be explained by the fact that the NSB reports use the notion of a technology leader, whereas our PTCE model concentrates on particular components of such a position. The NSB (2020) report shows a rapid growth of PRC's competitive position towards the USA in knowledge and technology. USA is still the leader in R&D expenditures and production of highly cited scientific papers, PRC on the other hand is considered to be a major rival of USA with rapidly developing science and engineering capacity. The World Bank [WB] report on innovativeness proves that the PRC became a leader in exports quantity, but not quality, with Germany, South Korea, Japan and USA (leader) surpassing it (WB, 2019). Surprisingly, our study shows that already in 2004 PRC's comparative advantage in high-tech exports was higher that the USA's.

Global Innovation Index [GII] published by the World Intellectual Property Organization [WIPO] uses similar indicator to our PTCE. The 2020 report confirms our findings, with USA (3rd) dominating the PRC (14th) in a contest of 131 countries (WIPO, 2020), as is the 2009–2010 report published back then by Institut Européen d'Administration des Affaires [INSEAD]. In 2010, the USA held significantly higher place (11th) than the PRC (44th) (INSEAD, 2010), whereas in 2007 the USA was 1st and PRC 29th – both countries kept an upward trend (INSEAD, 2007). Worth noting, the lowest position of the USA in this ranking was 11th (2009–2010), while the highest position of the PRC was 14th (2019–2020). Our findings coincide with PRC' trends, but those of USA are opposite. GII reports (INSEAD, 2007; INSEAD, 2010; WIPO, 2011–2020) back our findings by proving, that in the studied period, the PRC held a way lower position than the USA.

Our approach to measuring technological competitiveness of economies is not the only one, which can be found in the literature. Some authors derive it from the advancement of country's military innovations, e.g. (Wilczyński, 2013).

To summarize, our results and those of other researchers seem to confirm a trend discovered already by Porter et al. (2009), which shows a rapprochement of PRC's and USA's technological competitiveness, with USA maintaining its position – at least for now. At the same time Jacques stated that PRC already surpassed USA in field of competitiveness of economy, particularly in export including high-tech, which resulted in "huge trade deficit between the two countries" (2009, p. 350). Table 5 provides a reference of our findings to the competitiveness of economies of PRC and USA in past two decades.

Table 5 concludes our study by providing a juxtaposition of results of other scientific works on a similar subject and mostly confirming our findings. Strongest similarities can be found in trends and positions in economic competitiveness of PRC and USA. Main differences lie in employed research methods and indicators, however some studies are based on similar indexes. Most authors tend to agree with thesis that USA had a significant TCE over PRC, however the technological distance between these two economies is shrinking, as we prove by confirming all formulated sub-theses, and therefore the MRT.

The final chapter summarizes our research by a brief conclusion.

6. Conclusions

In this paper we presented an innovative and comprehensive analysis of the technological competitiveness between the USA and PRC using our original Pentagon of Technological Competitiveness of Economy (PTCE) method. The novelty of the model lies in the utilization of five revealed comparative advantage indexes which collectively offer an assessment of the technological competitiveness of an economy. The incorporated indicators encompass STEM-related patents, STEM-related scientific articles, R&D expenditures, researchers and

Table 5. Results of past studies on the competitiveness of economies of PRC and USA in relation to our findings on technological competitiveness of economies (source: authors' own elaboration based on literature review)

Source	Trends[a]		Position	
	PRC	USA	PRC	USA
Rojo (2022)	similar	reverse	similar	similar
Dai and Tan (2022)	similar	reverse	similar	similar
Vo and Tran (2022a)	similar	reverse	similar	similar
Li et al. (2022)	similar	similar	similar	similar
IMD (2022)	similar	similar	similar	similar
INSEAD (2007–2010), WIPO (2011–2020)[b]	similar	different	similar	similar
NSB (2020)	similar	reverse	similar	similar
WEF (2004–2020)	similar	similar	similar	similar
WB (2019)	similar	similar	similar	similar
Basu et al. (2018)	similar	similar	similar	similar
Wei et al. (2017)	similar	not included	similar	similar
Blank (2016)	similar	similar	similar	similar
Brooks and Wohlforth (2015)	not conclusive	not conclusive	similar	similar
Huang and Sharif (2015)	similar	not included	similar	similar
Zamora-Torres (2014)	not included	not included	similar	similar
Atkinson and Andes (2011)	similar	reverse	similar	similar
Porter et al. (2009)	similar	similar	similar	similar
Andrew et al. (2009)	similar	similar	similar	similar
Porter et al. (2008)	reverse	reverse	similar	similar
Newman et al. (2005)[c]	similar	different	similar	similar

Note: [a]Forecast for any time period covered by our research (2000–2020, where applicable); [b]In years 2007–2011 Global Innovation Index was published by INSEAD, and in 2011–2020 by WIPO; [c]Studied period covered change between years 1993–2003.

high-tech exports. By introducing the PTCE method and revealing the potential for a rank reversal, we provided valuable insights for policymakers and public managers. This study opens avenues for further examination of the qualitative aspects and the development of more comprehensive forecasting models in the field of technological competitiveness.

Our study confirmed the USA's current position as a global technological leader. However, what set our research apart is the identification of the PRC as a country that constantly challenges the USA's technological competitiveness. This finding unveiled a potential rank reversal in the near future, adding a new dimension to the economic and technological rivalry between the two nations.

The implications of our findings are profound for public managers in both the USA and the PRC.

For the PRC, our research highlighted the importance of sustaining their upward and indicator-balanced trend. By focusing on maintaining their growth trajectory in key technological indicators, the PRC can become the global technological leader in the near future. But our findings also show that for the PRC strategic investments in research, innovation, and human capital development are crucial in this race. The PRC has an opportunity to surpass the USA in technological leadership by strategic investments in research, innova-tion and human capital development.

For the USA to maintain its technological leadership, it is essential to restore the upward trend in every indicator (except for RECA) and critically evaluate the reasons behind RECA's domination. Policymakers in the USA should prioritize enhancing capabilities in areas such as patents, scientific articles and the export of high technology and STEM-related products to reinforce its position as the unrivaled technological leader.

Both countries should keep track on changes taking place during fourth industrial revolution and develop strategies such as "Made-in-China 2025" to deal with rapid technological changes in current world. It is crucial for policymakers to secure the growth in science- and technology-intensive economy sectors as it's the driver of long-term economic development.

The limitations of our research were the following: (i) due to lack of complete data-sets it doesn't cover the 2021–2022 time period; (ii) low credibility of PRC's official statistical data sets; (iii) limited access to scientific papers in Chinese language on the studied issue; (iv) our research covered the quantitative aspect of the research problem, without going deeper into qualitative details.

Directions of future research should focus on: (i) understanding the qualitative reasons and implications of RECA domination for the USA; (ii) expanding the PTCE model with qualitative TCE indicators; (iii) creating reliable TCE forecasts for technological competitiveness in the future; (iv) tracing the evolution of "high-tech exports" definitions in scientific literature and global data bases throughout the studied period (v) qualitative analysis of PTCE components (vi) studies on original RECA, RDCA and RSCA indicators (vii) using PTCE to compare results for blocks of countries e.g. BRICS, E7, EU (viii) estimating the relationship between PTCE and existing competitiveness models alongside with country rankings (ix) adding the geopolitical component to future studies on the technological competitiveness of economies.

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Author contributions

AW and RG conceived the study. RG was responsible for the research design, methodology, conceptualization and addressing Reviewers' suggestions. AW was responsible for data collection, curation and analysis and proposed the Pentagon of Technological Competitiveness of Economy model. AW and RG were responsible for data interpretation. AW and RG wrote the first draft of the article, as well as its final form. The contribution share of authors is equal and amounted to 50% for each of them.

Disclosure statement

Authors declare that they do not have any competing financial, professional, or personal interests from other parties regarding this research.

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