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Industrial Revolution 4.0 in the BRICS countries: What are the challenges for industrial policy?

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Abstract

Long-term scenarios predict that the BRICS countries can overtake the G7 countries in their contribution to the world economy, but, as follows from the analysis of multicomponent international indices, the same countries lag significantly behind the G7 countries in terms of preparedness for a technological future. In this regard, the growth prospects of the BRICS economies are largely determined by possible strategies of the countries to disseminate and use the Fourth Industrial Revolution (Industry 4.0) technologies.

Analysis of TiVA OECD data revealed that BRICS was not very profitably integrated into global value chains — far from the final consumer abroad and relatively close to suppliers of raw materials and semi-finished products — which in the long term determines the limitations on increasing economic complexity. Analysis of the WITS World Bank data revealed that BRICS was relatively poorly involved in the processes of international exchange of products related to the technologies of Industry 4.0 — industrial robots, additive technologies, computer-aided-design and computer-aided-manufacturing technologies, and biotechnologies — and retained the position of net importers, with China making the greatest contribution to the dynamics of trade.

Taking into account the general growth of global competition for technologies associated with Industry 4.0 and the continuing lag of BRICS in creating and using such technologies, the authors highlight the challenges for the industrial policy of the BRICS countries and discuss possible answers within the framework of industrial and trade policies. Challenges for BRICS include continued participation in global networks as countries serving the production and trade of new

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technologies; lagging behind in the level of development of the institutional environment and infrastructure for development of technologies; formation of limited "hotbeds" intensively using the Industry 4.0 technologies; and, thus, growth of spatial, inter- and intra-sectoral inequality.

Keywords: Industry 4.0, BRICS, robotization, digitalization, global value chains, technological renewal.

JEL: F23, L52, O14, O33.

Introduction

The scale and depth of the currently occurring technological changes make it possible to discuss the approach of the next — the fourth in a row — industrial revolution. In a relatively narrow context, it is customary to correlate it with "end-to-end" digitalization, which encompasses all physical assets and ensures the integration of all links of technological chains into common digital ecosystems (PwC, 2016). In a broader sense, the Fourth Industrial Revolution (Industry 4.0), in addition to the digital block of technologies, also includes the physical and biological blocks (Schwab, 2016). Additionally, the range of technological areas underlying the current revolution is wide and includes, for example, artificial intelligence, robotics, smart sensor systems, blockchain, additive technologies, new materials, new computing technologies, biotechnology, and neurotechnology (World Economic Forum, 2018).

The introduction of Industry 4.0 technologies is expected to reshape competitiveness and redistribute the direction and magnitude of global labor and capital flows.

On the one hand, the growth of industrial automation and the use of three-dimensional printing technologies, which have gained high growth rates in developed countries, can undermine the traditional competitive advantage of developing countries in low labor costs (Hallward-Driemeier & Nayyar, 2019). 3D printing technologies in factories will eliminate the need to reconfigure supply chains for innovative products and the costs of assembling intermediate parts and depreciating ancillary equipment, thereby reducing the demand for intermediate goods, making the intermediate stages more vulnerable and depriving developing economies of a comparative advantage in cheap production factors (Porter & Heppelman, 2014; Sasson & Johnson, 2016). As a result, the technologies of Industry 4.0 can strengthen the desire of developed countries to reshore and return industries that were once transferred to developing countries. This could significantly affect the manufacturing sector and industries of traditional specialization in developing countries, including the BRICS (Brazil, Russia, India, China, and South Africa) countries,[1] as well as reduce the volume of foreign direct investment (FDI) in these countries. In particular, some signs of a shrinking in the FDI market from countries with the highest levels of robotization to developing countries were already observed in 2000–2010s (Hallward-Driemeier & Nayyar, 2019).

[1] This will affect Brazil, Russia, India, and South Africa first, because China stands out significantly among BRICS in terms of the level of production automation and the number of patents associated with Industry 4.0 (Leistner, 2018).

On the other hand, the Internet of Things (IoT) technologies will provide greater data exchange between companies, suppliers and buyers, increasing the strength of supply chains by making them less dependent on the human factor. This will increase the competitiveness of less developed countries with low levels of human capital to host the stages of global production (Tang et al., 2018).

In general, Industry 4.0 technologies will lead to the fact that comparative advantage in production — in a broad sense — will be determined not by the relatively low labor intensity of production and cheap raw materials (which was characteristic of the comparative advantages of developing countries during the second half of the 20th century), but by the capital to labor ratio and availability of highly qualified employees in the country, because semi-skilled labor will be largely replaced by industrial robots.

These trends will lead to a change in the principles of forming a comparative advantage at the firm level. For the past 20 years, it has been generally accepted that the key factor in a firm's participation in international trade was the level of productivity.[2] Industry 4.0 technologies, such as additive technologies, will significantly reduce the minimum effective level of return to scale for traditional industries (Laplume et al., 2016). This phenomenon will allow more firms to participate in global production and, as a result, increase competition in the global market, with the winners being the firms that can be the first to move to new technologies.

Industry 4.0 will significantly change the organization of global value chains (GVCs). Global chains will continue trends associated with lengthening and increasing specialization (World Bank, 2019). The introduction of Industry 4.0 technologies will also expand the geographic dispersion of the GVC member countries in the final stages of production near the final consumer. The IoT technologies will change the organization of geographically distributed value chains by simplifying the coordination of individual stages of production (Strage & Zuchella, 2017; Alcacer et al., 2016). This will significantly affect those chains where it is important to trace the place of origin of a product and the stages of its processing, which is primarily in agriculture (e.g., in the production of coffee, cocoa, and organic products). Robotization will allow a significant increase in labor productivity in a short time, especially in labor-intensive sectors (e.g., agriculture, woodworking and furniture production, textiles, and clothing production).

Research on the challenges of Industry 4.0 has focused primarily on the United States, Europe, and some Asian countries, but not on the BRICS countries (Menelau et al., 2019; Rüßmann et al., 2015). However, for the BRICS countries, these challenges may be the most powerful. In the early 2000s, and even more in subsequent decades, the BRICS countries were expected to increase their role in the global economy, collectively overtaking the G7 countries in economic potential (Wilson & Purushothaman, 2003). However, Industry 4.0 may become an obstacle for BRICS in implementing this scenario, because these countries (at least compared with the G7 countries) have a significantly smaller pool of skilled labor, lag behind in the development of modern infrastructure,

[2] Only at a certain level of productivity can a company overcome the costs of exporting and entering foreign markets (Melitz, 2003).

and risk losing the status of global production sites (primarily China, see Jiao (2018), Kuzyk et al. (2020)).

1. BRICS' readiness for Industry 4.0

Considering the complexity of the processes and changes generated by Industry 4.0 at the level of world and national economies, and, consequently, the variety of challenges and opportunities arising in this regard for different countries, it is advisable to use international indices reflecting the readiness of national economic systems to function in new conditions in order to obtain a somewhat holistic picture of the BRICS countries' readiness for the industrial revolution.

The Networked Readiness Index (NRI) is calculated on the basis of more than 60 indicators in four areas — technology, governance, people, and influence — and aims to assess factors, implemented policies, and institutions that enable countries to use information and communication technologies (ICTs) for sustainable growth, competitiveness and welfare (Portulans Institute, 2019). BRICS is in the middle of the ranking both in terms of the integral index and all its components; thus, if the average value of the index for the G7 countries is 74.8, then for the leading BRICS countries, for example, China, it is 57.6. Additionally, based on China's positions in certain sub-indices, its main competitive advantages are the developed legislative regulation of Internet commerce, the prevalence of broadband Internet access, public confidence in the Internet, a high share of business in R&D financing, the stimulated role of public procurement in the development of innovations, a significant share of high-tech export, and good quality of teaching mathematics in schools. Besides, the regulatory environment in the ICT sector in general, along with environmental pollution and poor use of "clean" technologies and fuels by the population, are the main weaknesses of China in this index.

Russia ranks second among the BRICS countries regarding the values of the sub-indices, is the leader in the use of "clean" technologies and fuels by the population, and is ahead of the vast majority of countries in some human capital characteristics: the quality of higher education, literacy rate, and proportion of qualified personnel. The weakest aspects of Russia in the framework of the index are in the sphere of state regulation: insufficient level of ensuring the rule of law, poor quality of regulation in general and of the regulatory environment in the field of ICT in particular.

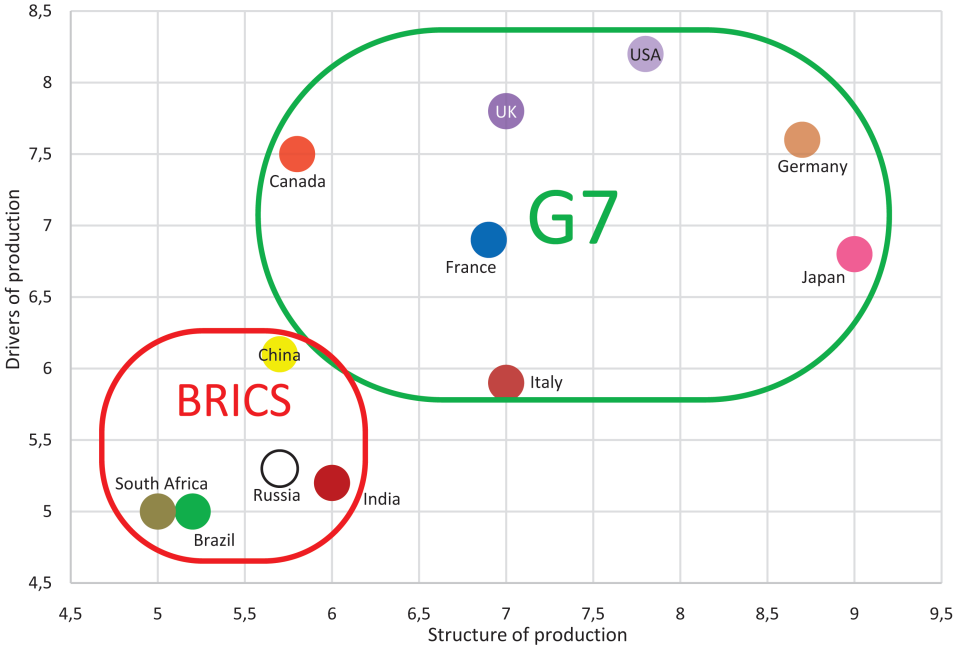
Brazil has the highest ratings for the use of clean technologies and fuels by the population and for the quality of government websites and e-services. Additionally, the overall quality of the use of ICTs by government agencies, as well as income inequality and a number of indicators of the regulatory environment are at the opposite "pole": the overall quality of regulation, ease of doing business, and the speed of adaptation of legislation to the requirements of digital transformation.

A significant competitive advantage of South Africa within the index is the developed legislation in the field of e-commerce. Weaknesses include quality of life indicators, primarily income inequality, and low life expectancy, as well as low transport security and an insignificant share of skilled workers.

Finally, India, an outsider in BRICS within the framework of the index, nevertheless has some advantages: high quality of state electronic services and websites, public confidence in the Internet, and the role of public procurement in stimulating innovation. However, the range of weaknesses is much broader and includes the overall low level of Internet connection of the population, environmental pollution, problems in providing the population with basic sanitation and drinking water, low satisfaction with the quality of life and its expected duration, and an insignificant share of qualified workers.

An alternative view of the level of the countries' compliance with the needs and requirements of Industry 4.0 is provided by the *rating of readiness for the future of production* calculated on the basis of 55 indicators in the context of two "dimensions": the structure and drivers of production (World Economic Forum, 2018). Notably, when calculating the rating, absolute indicators are used, which to a certain extent "favors" the largest economies.

In general, the BRICS countries are noticeably inferior to most of the leading industrial countries (in particular, those in the G7), both in the "structural" dimension, reflecting the scale and complexity of production, and in terms of its drivers: technology and innovation, human capital, global trade and investment, institutional conditions, resources for sustainable development, and demand conditions. In addition, the differences between the BRICS countries in terms of aggregate indicators are relatively small and noticeably inferior to the cross-country differences in the G7 countries.

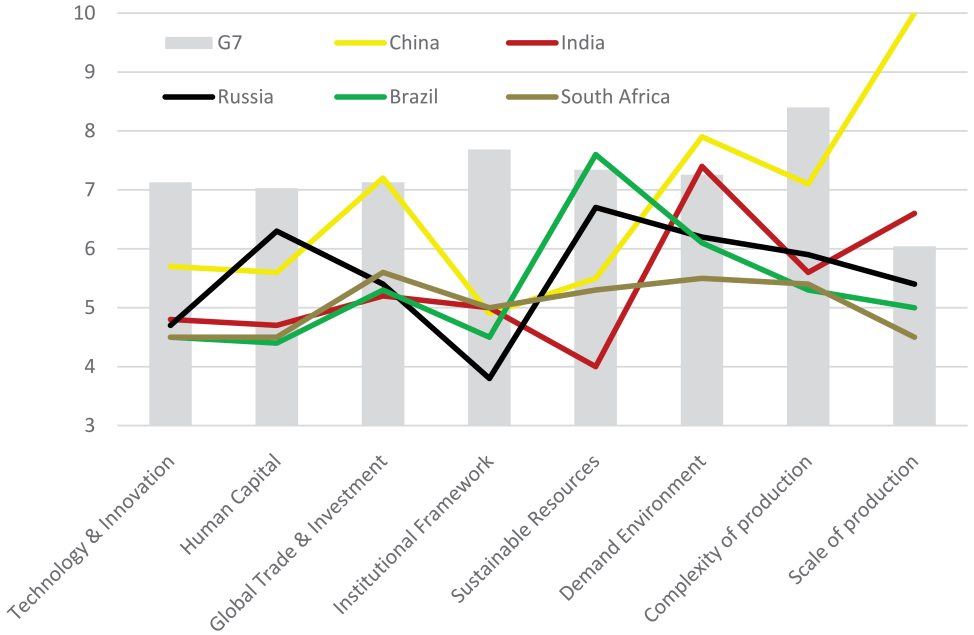


Sources: (World Economic Forum, 2018), authors' calculations.

Figure 1. Components of the readiness for the future of production in BRICS and the G7 countries

BRICS lags far behind the G7 in terms of the institutional conditions for the economy of the future. In addition, with the exception of China, the BRICS leader in most sub-indices, BRICS lags behind the G7 in terms of technology and innovation, global trade and investment, and manufacturing complexity.

The main competitive advantages of China in the ranking are the large absolute and relative size of the manufacturing sector, the total volume of domestic and foreign markets, as well as the scale of foreign direct investment — according to the corresponding sub-indices, China is the world leader. Besides, China's strengths include the contribution of public procurement to innovation, the quality of universities, the volume of venture capital investments, domestic lending to private businesses, and consumer demand. The key disadvantages of China in terms of the ranking are relatively weak mobile penetration, low average duration of education, high intensity of CO_2 emissions, as well as indicators of foreign trade: a relatively small share of foreign trade in gross domestic product (GDP) and high tariff barriers.



Sources: (World Economic Forum, 2018), authors' calculations.

Figure 2. Values of the main sub-indices of the rating of readiness for the future of production in the BRICS and G7 countries (average level for the group)

India's strengths are largely the same as China's: the scale of the manufacturing sector, the volume of domestic and foreign markets, the contribution of government procurement to the development of innovation, the volume of venture capital deals, the scale of FDI, and high consumer demands. A number of disadvantages also coincide: weak mobile penetration, low average duration of education, an insignificant share of foreign trade

operations in GDP, high tariff barriers, and high intensity of CO_2 emissions. However, India also faces specific problems, such as a low share of Internet users, an underdeveloped electricity infrastructure, ineffective regulations, a low proportion of women in the labor force, low school life expectancy, insufficient number of teachers in schools, and problems with water supply. Overall, in terms of sustainable development, the country is in one of the worst positions.

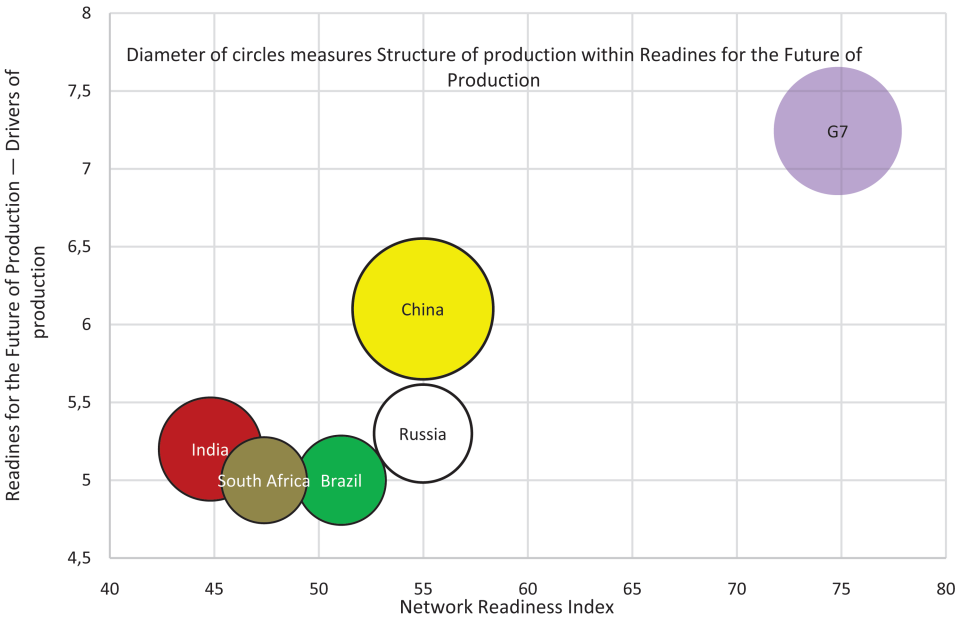
The relative competitive advantages of Russia are again the scale of the manufacturing industry, the quality of universities, the volume of FDI, the volume of venture capital transactions, and the size of the domestic and foreign markets. In addition, Russia has specific advantages in the field of ICT and human capital, the main of which are the share of mobile subscribers, cybersecurity, the share of highly skilled workforce, and the labor force of women. Notably, Russia ranks high in the group of sustainable development indicators, which, however, is combined with a relatively small share of alternative and nuclear energy and significant emissions of CH_4 and, especially, CO_2. Russia's weaknesses are predominantly concentrated in two areas: first, the institutional environment, which is characterized by ineffective regulation, high levels of corruption, and insufficient provision of the rule of law; second, foreign trade, which is associated with a low share of foreign trade transactions in GDP, a significant role of non-tariff barriers, and low efficiency of the distribution network. In addition, the low inflow of new technologies through FDI and the weak impact of ICT on the creation of new business models are also significant problems.

Brazil's key competitive advantages are concentrated in the field of investment — in terms of FDI, venture capital, and sustainable development. Besides, the country has a significant added value in the manufacturing sector (with a relatively modest share in the economy), a significant volume of domestic and foreign markets, and relatively high-quality universities. Weaknesses, on the other hand, are foreign trade (i.e., its relatively small share of GDP, high tariffs, and significant non-tariff barriers) and human capital (i.e., insufficient duration of training; low availability of scientists and engineers; low prevalence of digital skills among the population; poor quality of professional, mathematical, and science education; insufficient training of critical thinking; ineffective policies for the unemployed, and lack of flexibility). The low role of public procurement in stimulating innovation is also one of the main disadvantages.

South Africa, with low values of the dominant part of the sub-indexes, is characterized by a higher quality of its distribution network and its significant internal lending to the real sector, as well as a relatively high level of consumer demand. The most significant shortcomings are concentrated in the area of human capital: poor dissemination of digital skills among the population, low availability of scientists and engineers, insufficient quality of mathematics and science education, insufficient number of teachers in schools, ineffective policies for the unemployed, and insufficient flexibility of employment and dismissal legislation. In addition, the country is experiencing challenges of sustainable development, primarily the high level of CO_2 emissions.

A joint review of both indices shows more clearly that BRICS is significantly behind the G7 countries in terms of the level of readiness of national economies for Industry

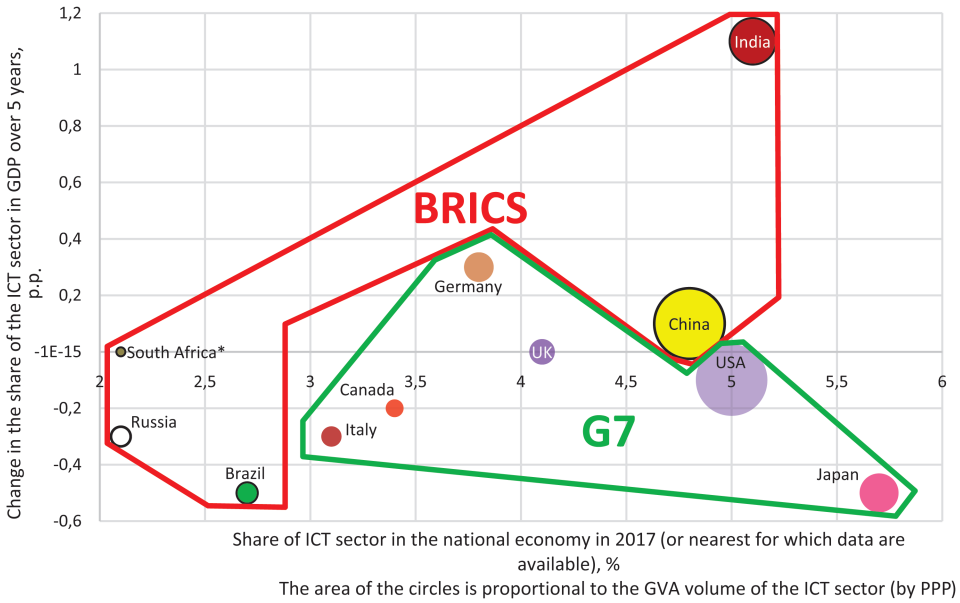
4.0. The positions of BRICS in the composite indices are very close (with significant differences at the level of individual indicators); however, China leads this close group in both components of the rating of readiness for the future production and is at least as good as them in the NRI. The hierarchy of other BRICS countries is less obvious, but it is noteworthy that Russia, along with China, is ahead of the other countries in terms of the NRI and is at approximately the same level as them in terms of future production drivers (Figure 3).



Sources: (World Economic Forum, 2018; Portulans Institute, 2019), authors' calculations.

Figure 3. Comparison of the BRICS and G7 countries (group average) in terms of the NRI and components of readiness for the future of production

The central element of the Industry 4.0 is the ICT industry. The absolute size of the relevant sector in the BRICS countries varies by more than an order of magnitude: from approximately $1.5 billion in South Africa to almost $10 billion in China (in terms of purchasing power parity, PPP), which, along with the United States, is the world leader in this regard. However, regarding the share of the ICT sector in GDP, most of the BRICS countries are close, but noticeably inferior, to the most economically and industrially developed countries (i.e., the G7 countries) and show a similar five-year dynamics of this indicator (neutral or close to it — within 0.5 p.p. of GDP). Additionally, China and India are among the world leaders in the contribution of the ICT sector to GDP, significantly ahead of other BRICS countries, and in the case of India, this phenomenon was largely due to the recent outstripping growth of this sector.



Note: for South Africa, data on dynamics are available only for 2014 and 2015.

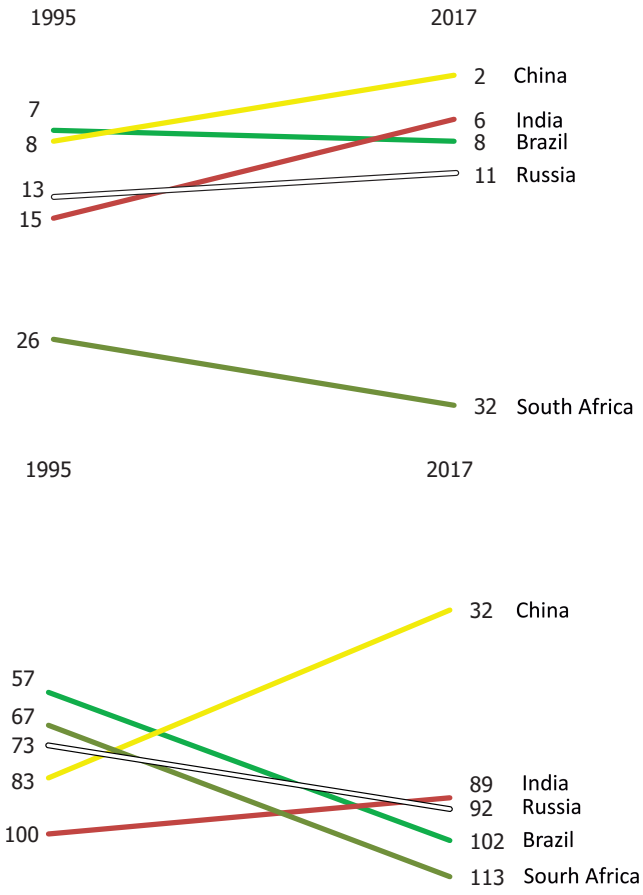
Sources: (UNCTAD, 2019; OECD, 2020), authors' calculations.

Figure 4. Comparison of the share of the ICT sector in GDP and its dynamics over five years in the BRICS and G7 countries

2. Positioning of BRICS in the world economy in the context of Industry 4.0

The peculiarities of the world economy at the present stage determine that long-term economic growth rates are provided only in the case of structural changes leading to complications of the economy and technological renewal. Over the past two decades, BRICS has doubled its contribution to world production, and its share in global GDP in 2018 was 23.5%. Within BRICS, China is the main driver of growth. Only China has made a significant breakthrough in the level of economic complexity among the BRICS countries. From 1995 to 2017, the Chinese economy rose from 83rd to 32nd position. India climbed 11 places in the world rating in terms of economic complexity, while Brazil, Russia, and South Africa are close to the end of the top 100 countries.

The differences in the growth characteristics of the BRICS countries are a good illustration of modern views on the formation of the bipolar world. Today, it is estimated that 25 countries produce approximately 75% of the world's value added, and these countries will continue to increase their advantage in the coming years, while the rest of the countries risk maintaining their low rates of economic growth. Among BRICS,



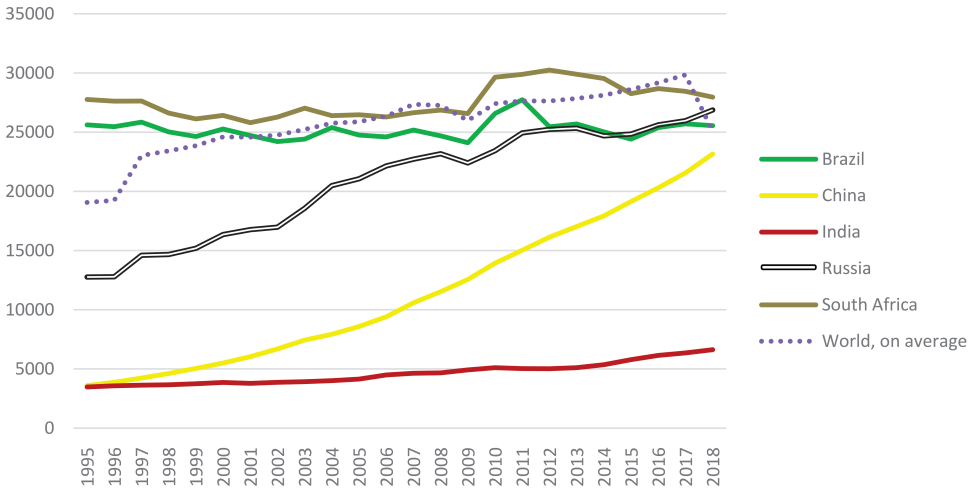
Sources: authors' calculations, data from World Bank, Atlas of Economic Complexity.

Figure 5. Positions of the BRICS countries in the world economy in 1995 and 2017 in terms of absolute GDP (*upper*) and economic complexity (*lower*)

only China is in the top 25 leading countries. In 1995–2017, industrial productivity in China increased at an average rate of 8.1%, while in other BRICS countries, productivity growth lagged significantly behind this.[3] The average annual labor productivity growth rate in Russia and India was 3.2% and 2.7%, respectively. In Brazil and South Africa, productivity in 2017 remained unchanged since the mid-1990s.[4]

[3] Low rates of productivity growth in the BRICS countries (excluding China) were identified: (1) weak structural changes in the economy and large participation of the informal sector in the economy due to productivity growth mainly in the raw material sectors; (2) growing differences in productivity between firms as a result of imperfections and limited competition in markets; and (3) inefficient distribution of capital and, partly, labor between and within industries (Dutz, 2018; De Vries et al., 2012).

[4] Estimates use data on the dynamics of value added per one employed person in an industry (including the extractive, manufacturing, and construction sectors); estimates are provided in constant prices for 2010.



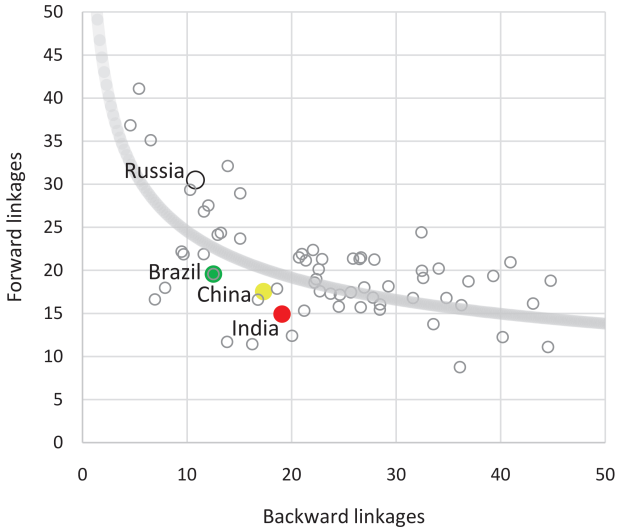
Note: as a measure of productivity, value added per employee in an industry (including mining, manufacturing, and construction) is used; the data are given in constant prices for 2010.

Sources: authors' calculations, World Bank data.

Figure 6. Industrial productivity in BRICS and in the world on average from 1995 to 2018 *(USD)*

In the face of weak structural changes in their economies, the BRICS countries, with the exception of China, continued to act mainly as suppliers of traditional goods with low value added to world markets (Kuzyk et al., 2020). The growth of commodity exports in Brazil, India, Russia, and South Africa in 2000–2017 was determined by the expansion of exports of raw materials, as well as goods of low value added (e.g. oil and petroleum products, agricultural complex, metals, basic chemicals). This determined their special positioning in GVCs — far from the end consumer abroad. Additionally, the relatively weak development of manufacturing industries and measures aimed at import substitution and cultivation of their industries determined a relatively short length of top-down relationships with suppliers of semi-finished products.

Changes in the organization of GVCs as a result of the introduction and diffusion of Industry 4.0 technologies are likely to have mixed consequences for BRICS. Nowadays, China is one of the three global hubs for GVCs, on a par with Germany and the United States. Resolving and changing the nature of comparative advantages create risks of a certain reduction in the interest of developed countries in the Chinese economy. Besides, the rapid development of its production base and, in particular, the outstripping pace of production automation is likely to maintain China's leadership as a global manufacturing hub. In addition, the rapid development of China's scientific productivity in the field of research in Industry 4.0 is likely to maintain China's leadership in the field of scientific potential (Menelau et al., 2019), which will largely reinforce its leadership in the production sector. The potential of the domestic market and that of neighboring countries continues to define great opportunities for Brazil, Russia, India, and South Africa to integrate



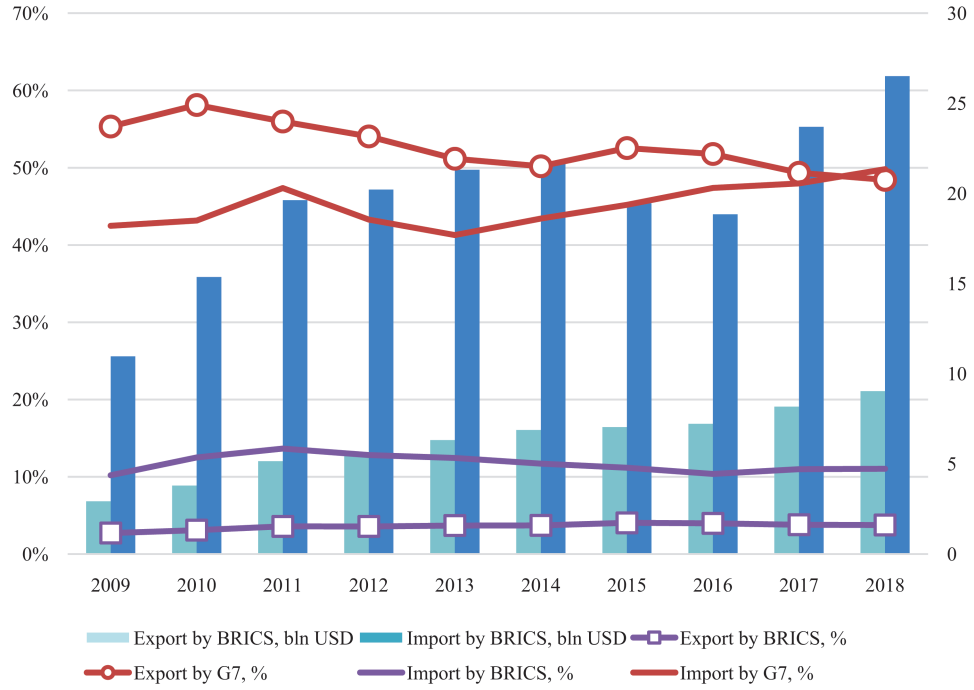
Note: backward participation in GVCs represents the foreign value added from "partner" country *P* embodied in the gross exports of country *C* (*% of country C's total gross exports*); forward participation in GVCs represents the domestic value added from country *C* embodied in the gross exports of "partner" country *P* (*% of country C's total gross exports)*.

Sources: authors' calculations, TiVA OECD data (for South Africa is not available).

Figure 7. BRICS' participation in global value chains as of 2015

into global chains and form regional hubs of global production. This potential can be realized if these countries, can introduce Industry 4.0 technology in a short time, and thus make a leap forward, because previously this leap was usually associated with significant investments in fixed assets, but now, in the context of Industry 4.0, this potential is largely determined by intangible assets and the level of human capital, which remains one of the key advantages of Russia over other BRICS countries.

We witness an increasing competition in international trade of products related to Industry 4.0 technologies. Thus, although the BRICS countries have maintained their position as net technology importers over the past decade, the G7 countries have significantly reduced their net exports and are likely to become net importers in the next decade as well. The decline in the G7 net exports is mainly due to changes in the US net trade balance, which has changed from a net exporter to a net importer position. In contrast, Germany, for example, continues to be a net exporter of products related to Industry 4.0 technology. According to our estimates, between 2009 and 2018, the BRICS' share of international trade in products related to Industry 4.0 technologies averaged 3.6% of world exports and 11.7% of world imports (Figure 8). The driver of exports and imports among the BRICS countries was China, for which exports and imports of products related to Industry 4.0 technology more than tripled, accounting for approximately 78% of gross exports and approximately 58% of gross imports of BRICS.



Note: trade in industrial robots, additive technologies, computer-aided design and computer-aided manufacturing (CAD/CAM) technologies, and biotechnologies is taken into account. The cost of exporting and importing industrial robots, additive technologies, and CAD/CAM technologies was calculated in accordance with (Foster-McGregor et al., 2019). Export and import of products related to biotechnologies is given according to the US Census ATP list.

Sources: authors' calculations, World Bank data.

Figure 8. Exports and imports of Industry 4.0 technologies by BRICS and the G7 countries, 2009–2018

The relatively low participation of BRICS in the international trade of products related to Industry 4.0 technologies determines the relatively low potential of these technologies in the manufacturing sector. According to our estimates, in BRICS, the average use of imported Industry 4.0 technologies is USD 508.6 per employee, whereas in the G7 countries it is 18 times higher: USD 9,149.3 per employee (Table 1). The revealed difference is most pronounced when using biotechnology — 30.7 times and slightly less — but is significant when using robotics, additive and CAD/CAM technologies (5–6 times). Within the BRICS countries, a relatively higher share of technology imports is typical for South Africa, Russia, and Brazil, but this should not be attributed to their leadership and greater availability of imported technologies in production. This is a consequence of significantly lower industrial employment in these countries compared to India.[5]

[5] According to our estimates based on the World Development Indicators, the number of people employed in industry in Brazil is 21.2 million; in Russia – 19.8 million; in South Africa – 5.3 million; in China – 220.9 million; and in India – 121.7 million.

Table 1. Volume of exports and imports of products related to the technologies of Industry 4.0 in 2009–2018, cumulative total *(dollars per person employed in industry)*

	Export					Import				
		Including:					Including:			
	Total	Industrial robots	Additive technologies	CAD/CAM technologies	Biotechnologies	Total	Industrial robots	Additive technologies	CAD/CAM technologies	Biotechnologies
Germany	25 566.8	539.5	4 725.9	2 399.0	17 902.5	18 593.3	333.8	1 083.9	996.1	16 179.4
UK	12 552.3	80.2	350.6	382.6	11 739.0	14 309.1	129.2	618.3	475.8	13 085.8
France	12 215.9	354.2	1 503.9	352.4	10 005.3	12 102.5	181.4	859.7	611.6	10 449.7
Italy	10 074.5	388.2	3 180.7	1 873.0	4 632.7	10 229.3	212.8	739.1	618.6	8 658.8
USA	5 888.1	62.3	474.2	182.4	5 169.2	6 534.0	78.1	800.3	506.8	5 148.9
Canada	4 615.5	133.0	2 168.4	136.0	2 178.1	9 658.1	190.6	1 247.7	719.2	7 500.6
Japan	4 422.8	869.1	1 457.0	1 663.6	433.0	3 990.3	21.0	311.8	144.6	3 512.9
G7 on average	**9 594.3**	**340.6**	**1 629.0**	**947.0**	**6 677.7**	**9 149.3**	**130.2**	**750.9**	**528.5**	**7 739.7**
China	218.7	6.3	137.8	28.8	45.9	471.5	37.0	137.7	112.2	184.6
South Africa	110.5	2.3	32.2	5.2	70.9	1 104.6	51.1	362.3	81.6	609.6
Russia	83.2	0.5	11.4	6.9	64.3	1 594.9	12.1	424.1	251.2	907.5
India	82.3	0.2	19.6	1.7	60.8	153.9	7.0	69.5	18.6	58.7
Brazil	76.6	0.4	28.1	9.5	38.6	1 763.7	42.8	255.5	101.2	1 364.1
BRICS on average	**159.9**	**3.7**	**87.0**	**17.8**	**51.4**	**508.6**	**26.8**	**140.5**	**89.0**	**252.3**

Note: trade in industrial robots, products related to additive technologies, CAD/CAM technologies, and biotechnologies is taken into account. The cost of the export and import of industrial robots, as well as products related to additive technologies and CAD/CAM technologies, was calculated in accordance with (Foster-McGregor et al., 2019). Exports and imports of products related to biotechnologies are according to the US Census ATP list.

Sources: authors' calculations, data from World Bank, World Development Indicators.

The difference in conditional productivity (production) of exports of products related to Industry 4.0 technologies is even more pronounced in BRICS than in the G7 countries: USD 159.9 per one employed against USD 9,594.3 (60-fold difference). China is the BRICS leader in specific exports of products related to Industry 4.0 technologies, although the largest industrial sector in terms of employment is USD 218.7 per employee, which is almost one and a half times higher than the average and more than twice as high as in other BRICS countries separately.

3. Political challenge

In general, today the BRICS countries are significantly inferior to the leading industrial countries in their *readiness* for Industry 4.0. The differences within BRICS, despite the fundamental differences in the scale, structure, and peculiarities of economic development, are not as great or are significantly smaller than, for example, in the G7 countries. Notably, the relatively good positions of countries in some components of the "readiness ratings" should not be interpreted as an advantage, but as a potential that requires additional efforts.

The spread of Industry 4.0 technologies creates a fork in long-term growth scenarios and future positioning of the BRICS countries in the global economy.

At one end of the fork is the risk of losing industrial jobs due to the loss of comparative advantages in trade and the departure of multinational companies from the BRICS countries.[6]

The risks of losing jobs are highest for such BRICS industries as mining, agribusiness, consumer goods, and some industries where the BRICS countries are involved in the processes of assembling and creating simple components for complex machinery, equipment, and electronics. In particular, this may lead to a stronger orientation of the economies toward the basic sectors and a worsening of the economic situation, because the released labor force as a result of the reshoring will be redistributed either to low-skilled industries or to shadow sectors of the economy. This will undoubtedly have a negative impact on the level of economic growth and prospects for structural transformation.

At the other end of the fork is an opportunity to retain jobs in the manufacturing sector and create new industries and jobs through the development of Industry 4.0 technologies. As for the structure of enterprises, it creates opportunities for growth in the BRICS small and medium-sized business sector, which is generally the most flexible of the sectors in terms of introducing new technologies.

In fact, an intermediate scenario, specific to individual BRICS countries, is likely to be implemented, given the differences within the BRICS group (Erro-Garcés & Aranaz-Núñez, 2020). Although the level of development of domestic technologies associated

[6] The last two decades have witnessed a reorientation of interest of multinational companies in the BRICS countries (Simachev et al., 2020). However, with the growing protectionism in the world economy, the growing sentiment for regionalization and reshoring, as well as the appearance of new attractive emerging economies from the "Group of Eleven" countries, the interest of IOCs in being based in the BRICS countries may significantly decrease.

with Industry 4.0 is relatively low in BRICS, the introduction of technologies related to Industry 4.0 in BRICS is linked with a different set of factors (e.g., underlying factors of capital and labor), which in the long run may lead the BRICS countries to different development trajectories.

First, the BRICS countries differ in the nature of their investment activities. Although China's accumulation of technological competences is currently mainly caused by investments, as well as its intensive acquisition of foreign technologies (in previous periods, through foreign investments, which are gradually being replaced by domestic investments), Brazil, Russia, India, and South Africa remain more dependent on foreign investments. Thus, the model of development based on foreign investments seems effective for countries as early as 20–30 years ago, but now, with protectionist sentiment and a clear slowdown in the activities of multinational corporations, it poses a serious threat to BRICS. High market capacity is becoming less important as a factor attracting foreign investments. Hence, an important issue on the economic agenda of Brazil, Russia, India, and South Africa is the search for additional attractive factors for foreign companies.

Second, the BRICS countries differ in the level of human capital. Russia's traditional leadership in the availability of a highly skilled workforce is no longer an advantage, because it reflects, first of all, basic skills and knowledge. However, the spread of Industry 4.0 technologies requires, above all, the ability to quickly retrain and develop specific skills, and to attract competitive human capital from developed countries, which is critical for BRICS (Aulbur et al., 2016). This is largely due to the leading role of government initiatives (Erro-Garcés & Aranaz-Núñez, 2020).

We posit that it is increasingly important to ensure public access to digital resources as a factor contributing to rapid learning and retraining. Additionally, for the large economies of the BRICS countries with uneven subnational (regional) development, it is particularly important to achieve equal access to digital technologies between and within regions.

Conclusions

Industry 4.0 presents significant policy challenges for BRICS. In particular, the new industrial policies exacerbate common challenges for the BRICS countries related to finding policies and building institutions that ensure high rates of economic growth (Wilson & Purushothaman, 2003). In this context, we highlight the following challenges for BRICS.

First, strategic trade policies should be implemented, including in order to develop a country and its sectoral priorities, and expand global production and scientific and technical cooperation. On the one hand, the regionalization of international trade and the continued heavy reliance on technologies associated with Industry 4.0 and developed in indusrialized countries pose challenges, particularly for Brazil, Russia, India, and South Africa, which creates risks of deficient acquisition of technologies and, consequently, an increase in the backlog in the long term. On the other hand, global trade conditions are changing, and large trading platforms are being formed. In these circumstances, it is

important to ensure fair conditions for entering such platforms while developing technical regulation and joint participation of the BRICS countries in the formation of international standards. Additionally, it is necessary to maintain a balance between inclusion in global processes and regionalization. The BRICS countries, in particular, are the largest countries in their regions of presence. This characteristic determines a high potential for reorienting economic ties, provided that access to advanced production technologies is maintained. As noted in the literature, this can be implemented by expanding existing agreements on scientific and technical cooperation and cooperation in the form of digital infrastructure development (Menelau et al., 2019; Banga & Singh, 2019).

Second, the role of the state in the economy and regulation of certain spheres must be reconsidered. In the context of the transformation of the environment, new technological opportunities contribute to mobility of business, expanding the geography of its interactions, and increasing the contribution of intellectual assets to its value. Simultaneously, new technological opportunities enhance sensitivity to the quality of government regulation and require the best approaches to protecting intellectual property. In this regard, the issue of ensuring the competitiveness of national jurisdiction becomes particularly important, and it is not so much a matter of greater or lesser participation of a state in the economy, but rather of a state performing positive functions in protecting the interests of national business in domestic and foreign markets, creating conditions for fair competition and thus attracting foreign investors.

Third, the accents in business support systems must be reconfigured. Technological and organizational changes lead to a reduction in the minimum business scale threshold for effective activity, and open up conditions for the formation of new companies. However, positive effects will be achieved in those BRICS countries where the motivation for entrepreneurship is more developed, with an emphasis on rapid business development and globalization.

Fourth, pilot regulations must be stipulated in the areas related to the development and implementation of Industry 4.0 technologies. New technologies often create a conflict between state regulation and private regulation of individual companies with advanced competencies and concentrated market positions. New business models are often a challenge to standard regulation. Previous approaches to regulating a number of new objects (regulation of platform monopolies, taxation of various transactions in the conditions of digital transformation, definition of responsibility for decision-making using artificial intelligence) are neither applicable nor limited. A number of technologies (e.g. artificial intelligence, genetic technologies) generate the strongest contradiction between ethical norms (cultural traditions) and possibilities of rapid technological progress.

Fifth, regional policies must be reviewed, including restructuring of regional strategies to overcome the challenges of Industry 4.0. The industrial revolution reinforces regional heterogeneity in development. For the BRICS countries with very heterogeneous levels of regional development, this challenge is significant and requires creating additional conditions for Industry 4.0 (human capital, ecosystems) in lagging regions and reducing inter-regional disparities.

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