DOI: 10.15838/esc.2023.3.87.15
UDC 330.341, LBC 65.9(4/8)

Evolution of the National Innovation Systems of the United States, the United Kingdom, China and Iran

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For citation: Volchik V.V., Tsygankov S.S., Maskaev A.I. (2023). Evolution of the national innovation systems of the United States, the United Kingdom, China and Iran. *Economic and Social Changes: Facts, Trends, Forecast*, 16(3), 284–301. DOI: 10.15838/esc.2023.3.87.15

Abstract. The concept of national innovation systems (NIS) involves consideration of the economic arrangements of individual countries. It is necessary to identify the features of institutions' evolution that contribute to the processes of creating and transforming knowledge into new technologies and products. The article examines the experience of developing the NIS of the USA, the United Kingdom, China and Iran. The US and the UK have stable and developed NIS with a long history. Thus, Iran and China can be classified as countries with developing innovation systems but demonstrating considerable success. The significant difference between the considered innovation systems is how countries achieve political and economic sustainability. All of them are trying to stimulate market mechanisms for creating innovations. The Chinese innovation model combines the promotion of grassroots innovation and government support for technology enterprises. In the US and the UK, the leading role of business is associated with the perception that it is better at distributing investment in R&D than the Government. Iran is also trying to stimulate private innovation, but the Government still plays the key role because of the limited domestic market and sanctions restrictions. One of the prerequisites for the development of the NIS of Iran and China is a long-term policy in higher education, which, combined with population growth, has led to a significant expansion of access to higher education. The article is of interest to the Russian scientific community since the authors, on the one hand, explore the NIS of the leading countries in the field of innovation located on different continents (the UK, the US and China) and, on the other hand, a country that has been under sanctions pressure (Iran), which is especially important in the current economic and political realities. The authors suggest thinking about possible ways of developing the Russian innovation system by analyzing the foreign experience of the NIS. Scientists who are involved in researching NIS and national innovation policymakers can use the results of this scientific work.

Key words: national innovation system, evolution, institutions, United States, United Kingdom, China, Iran.

Acknowledgment

This work was supported by the grant of Russian Science Foundation No. 21-18-00562, https://rscf.ru/en/project/21-18-00562/ "Developing the national innovation system in Russia in the context of narrative economics" at the Southern Federal University.

Introduction

The National innovation systems (NIS) came into the focus of scientific research at the end of the 20th century. At that time, within the framework of evolutionary economics, several scientific schools were formed, the efforts of which created the theoretical prerequisites for studying the NIS. The main element of the novelty in creating the NIS concept was to address the problem of national characteristics of the evolution of institutions that contribute to the processes of knowledge creation and their transformation into technology and new products[1].

[1] This approach to the definition of the NIS is reflected in S. Metcalfe: "[NIS] is a set of individual institutions which jointly and individually contribute to the development and dissemination of new technologies and provide the basis for the formation and implementation of public policies affecting the innovation process. In essence, it is a system of interrelated institutions for the creation, storage and transfer of knowledge, skills and artifacts that define new technologies" (Metcalfe, 1995, p. 38).

In the 1990s, in parallel with the NIS concept, the triple helix theory began forming, which emphasized the creation of an environment conducive to enhancing innovation processes in the interaction of three main actors: academia (universities), government and business (Etzkowitz, 1996; Etzkowitz, 2011). The development and complication of the triple helix concept in modern studies of innovation activity led to its transformation into the quadruple helix model, which adds a new element with a double structure: public, associated with media and culture, as well as civil society (Carayannis, Campbell, 2012, p. 13). The concept of the quadruple helix is closest to the theoretical framework of the NIS, as it explicitly emphasizes institutional factors (media, culture), which become particularly important for the creation and use of innovation.

In contemporary world, national innovation systems do not exist in isolation from each other, but differ in the degree of difficulty and complexity of development. For example, the U.S. NIS can be considered as one of the most complex, where the main components of the quadruple helix: academia, business, government regulation of innovation and the public (civil society) have evolved into an effective system associated with the production of a significant share of global innovations and innovative products (Alnafrah, Zeno, 2019).

The main hypothesis of the research work is that the successful functioning of the NIS requires the implementation of the previously highlighted three conditions of innovative development of the economy: political and economic stability, entrepreneurial initiative, increasing returns; and two prerequisites: development of market infrastructure and development of education and science (Volchik, 2022; Volchik, Maslyukova, 2022). The development of each of the national innovation systems has many points in common. Still, the most important in the context of this study is the emphasis on the specifics of the institutional structure and economic policy in the innovation sphere.

In this article, we consistently verify the presence of these three conditions and two prerequisites for the NIS of China, the United Kingdom, the USA and Iran, based on the available scientific papers, reports and statistical data of international organizations (the World Bank, Eurostat, WIPO, OECD, UNCTAD). *Table 1* presents the position of countries in the various world rankings.

Table 1. Position of countries in various world rankings

Rating (index) name	Place			
	United Kingdom	USA	China	Iran
GDP, 2021 (current U.S. dollars))[1)]	6	1	2	42
GDP per capita, 2021 (current U.S. dollars)[2)]	29	12	80	139
Global Innovation Index, 2022[3)]	4	2	11	53
International Property Right Index, 2022[4)]	17	13	47	113
Index of Economic Freedom, 2023[5)]	28	25	154	169
Global Soft Power Index, 2023[6)]	2	1	5	77
Readiness for frontier technologies index, 2023[7)]	17	1	35	75

[1)] https://data.worldbank.org/indicator/Ny.Gdp.Mktp.Cd?most_recent_value_desc=true
[2)] https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?most_recent_value_desc=true
[3)] https://www.globalinnovationindex.org/Home
[4)] https://www.internationalpropertyrightsindex.org/
[5)] https://www.heritage.org/index/ranking
[6)] https://brandirectory.com/softpower/
[7)] https://unctad.org/publication/technology-and-innovation-report-2023
Source: own compilation based on the listed indices.

The choice of countries is motivated by the following considerations. The U.S. and China are the world's largest economies, implementing different approaches to the formation and development of their NIS. The United Kingdom, in turn, is one of the leaders in the innovation sphere on the European continent. At the same time, the United Kingdom NIS has more independence, as after Brexit it is not part of the supranational innovation system of the European Union. As for Iran, its experience in building its national innovation system seems particularly interesting because the state has been under various economic sanctions for a long time, primarily on the part of Western countries.

China's national innovation system

Historically, the concept of China's technological development was shaped to overcome the legacy of the "century of humiliation" and create the basis of China's civilian and military capabilities, starting with Mao Zedong's policy based on "self-reliance" and ending with Xi Jinping's policy with increased emphasis on innovative development (Gaida et al., 2023, p. 15). In the initial stage of building a socialist economy, Soviet experience and Soviet scientific, technical, and economic assistance were greatly influenced.

Since 1978, China has begun implementing economic reforms, focusing on the development of market relations. The reforms were aimed not only at the evolutionary formation of market mechanisms, but also at the gradual opening of the economy to the increasing inclusion of China in the world economic relations system. The most important task during the reforms was economic modernization: "The strategy of the four modernization policies, which included agriculture, industry, national defense, and science and technology, became the most important flagship programs and national goals after the 1978 reforms" (Yi et al., 2021, p. 32). These reforms allowed not only the development of the construction of socialism with Chinese characteristics, but also, for the first time, the construction of an efficient and stable socialist market economy[2]. It was within the system of a socialist market economy that the NIS began developing vigorously. Highenr education and science development played the leading role in the modernization policy.

A major educational reform called the "Three Ds" began in 1985[3]. Along with the educational policy there was a policy aimed at encouraging the use of the results of intellectual activity in the real economy, called the "Three Cs"[4] (Klochikhin, 2016, p. 40–41).

In 1985, a decree of the Central Committee of the Communist Party of China was also adopted, which set the vector of departure from the Soviet innovation system model. Therefore, the main efforts were aimed at creating market incentives for the interaction of research institutes and universities with industry (Motohashi, Yun, 2007, p. 1251–1252).

[2] We should clarify that in this article we use the official designation of the economic system of modern China as a "socialist market economy". This type of economic order is characterized by the considerable development of market mechanisms and institutions and is actually a specific form of the market economic order with Chinese specifics. The key mechanism of economic coordination is still the market, but the economy is socialist because, thanks to the institutions formed by the Chinese Communist Party, the tasks of building a middle-income society, in which the political power of capital is greatly restricted, are solved.

[3] "The "Three Ds" include decentralization, depoliticization, and diversity. The management of local universities was transferred to the provincial and municipal levels. Universities were better able to develop their own teaching guidelines and courses without having to wait for political approval. The principle of diversity implied the introduction of a large number of new educational services, as well as the permission to open private universities and schools" (Klochikhin, 2016, p. 40).

[4] "The "Three Cs" are commercialization, competition, and cooperation. Universities have more freedom in establishing partnerships and contractual agreements with the private sector and local governments, in introducing tuition fees, and in developing mechanisms to compete for the best students, funding, scientists, and subsidies. (Klochikhin, 2016, pp. 40–41).

In the early stages, R&D activities were primarily demanded by large enterprises. Gradually, both private and state-owned enterprises formed their own research units. Moreover, studies of R&D returns depending on the form of ownership show that private enterprises get higher returns from their own R&D than state-owned ones (Boeing et al., 2016).

In the 2000s, China's innovation development took two paths: imitation of existing technologies and in-house innovation. Innovation and imitation organically complemented each other: "The findings on the complementarity of imitation and innovation show that imitation is not only a necessary strategy independent of innovation, but also vital for the effectiveness of innovation" (Wu et al., 2020, p. 748). For example, during the first decade of reforms, the Chinese innovation system faced a reduction in state funding of scientific and technological activities and a low level of industrial research and development (Xue, 1997, p. 79), but it was through consistent reforms and the development of the market segment of the innovation system that impressive results were achieved.

China's national innovation system is organized on several levels: at the top level the state and the Chinese Communist Party determine the main directions of innovation policy, at the middle level the regional authorities have some autonomy in conducting innovation policy (Gu, Lundvall, 2006) and at the lower level the entrepreneurial initiative (including large corporations) in implementing innovation is realized.

The development of the Chinese innovation system took place in a complex way. Still, when analyzing it, it is necessary to consider institutional and economic peculiarities and historical contexts. Ten years ago, China was lagging far behind developed countries in the share of R&D in GDP (1.7%). The emphasis was on applied research, and the share of basic research was only 4.7% in 2013 (Ding, Li, 2014, p. 383). But by 2018, China had already made impressive progress, becoming the world leader in the number of scientific articles and patents (Lundvall, Rikap, 2022, p. 5). In addition, China has developed large corporations (Baidu, Alibaba, Tencent, Huawei), which modern scientific literature refers to the class of corporate innovation systems[5].

It is necessary to consider the development's cultural and political features to understand which institutions and reforms contributed to this success. China represents a very specific economic order, so when analyzing the characteristics of the development of the Chinese national innovation system, we consider the duality of the policy and regulation brought in. This duality is based on a harmonious combination of the leading role of the Chinese Communist Party in the ongoing reforms and mechanisms of activation and use of grassroots initiatives for creating new products and technologies. The specific nature of the Chinese economy makes it difficult to copy the regulatory institutions of developed countries and determines the high adaptability of the ongoing innovation policy (Klochikhin, 2016; Gu, Lundvall, 2006).

Entrepreneurial specificity is very important for the Chinese innovation system: "Entrepreneurial activity from the bottom up, rather than state-led reform, has given rise to various new forms of entrepreneurship, capitalist economic institutions in China. Without codified property rights, these entrepreneurs spontaneously develop

[5] Lundvall and Rikap define the corporate innovation system as "sets of actors, activities, resources and institutions, and causal relationships that are in some sense important to the innovation activities of a corporation or groups of cooperating companies and other actors (e.g. universities, institutions, agencies)" (Lundvall, Rikap, 2022, p. 2).

informal rules and norms to overcome collective action problems. They create networks with other economic factors such as suppliers and distributors, create industrial clusters, and by trial and error create informal mechanisms to develop private manufacturing businesses" (Nee, Opper, 2012, p. 9). "These rules and practices emerging from below stimulate, motivate, and guide start-up firms, allowing private firms to survive and even catch up with state giants, while creating the institutional foundations of China's nascent capitalist economic order" (Nee, Opper, 2012, pp. 8–9).

China has made impressive progress in its catch-up model. But it is now becoming a full-fledged leader in technological and strategic innovation: "The foundations of recent economic success are being used to transform China into an innovative and green China. The strength of Chinese culture, such as the power of hierarchy and collectivism, is being used strategically. A holistic long-term pragmatic approach helps the Chinese see the national economy as a system that needs a comprehensive approach. The strong symbiosis between the Chinese government and Chinese firms forms the basis of a new sustainable growth curve" (van Someren, van Someren-Wang, 2014, p. 21).

In the example of the previously highlighted three conditions for the innovative development of the economy: political and economic stability, entrepreneurial initiative, and increasing returns – and two prerequisites: the development of market infrastructure and the development of education and science – (Volchik, 2022; Volchik, Maslyukova, 2022), we can characterize the features of the Chinese national innovation system.

Political and economic stability is ensured by a system of governance based on the dominance of the Communist Party and the implementation of the principle of democratic centralism. China's political and economic order can be called of democrat centralism by the title of Article 3 of the constitution, "The state authorities of the People's Republic of China shall implement the principle of democratic centralism"[6]. This political system definitely has significant differences from liberal democracy, but given China's specificity, it best ensures stability and sustainability. Moreover, contemporary China has managed to build a modern market economy under the political and economic order of democratic centralism.

The development of entrepreneurial initiative is provided, on the one hand, by the possibility of implementing grassroots initiatives under flexible institutional constraints, and on the other hand, by the government policy aimed at creating conditions for the entrepreneurship development. Contrary to stereotypes about Chinese interventionist government policy, measures to stimulate and provide resources for innovation activities in the Chinese context are predominantly market-based in nature (Băzăvan, 2019, p. 4).

The most important factor in the development of China's national innovation system has been the reform of education and science. During the reform period, the number of higher education institutions increased fivefold, and the number of students enrolled increased 23-fold (Gaofeng et al., 2021, p. 44). This impressive growth has affected the quality of human capital and created a significant foundation for the development of both industry and agriculture, as well as science and related industries that use and create technological innovation.

The significant growth in the number of students has made China the leading country in the number of graduates as well as doctors of sciences in natural science and engineering disciplines. China has surpassed Europe, the United States, and India in this regard (Gaofeng et al., 2021, p. 49).

[6] PRC Constitution (2018 edition). Available at: https://chinalaw.center/constitutional_law/china_constitution_revised_2018_russian/ (accessed: June 2, 2023).

According to the Australian Strategic Policy Institute (ASPI), China is currently the leader in 37 of 44 critical research areas for innovative development. Based on the analysis of scientific publications in 44 areas, the ASPI researchers developed a system of indicators to determine the risk of technological monopoly in each area. Based on this analysis, China has a high risk of technological monopoly in 8 research areas, and medium risk in 15. By comparison, the USA has only two items with a medium risk of technological monopoly (Gaida et al., 2023, p. 8).

In the area of innovative manufacturing, one of China's leading positions is held by digital Internet giants. Network effects and increasing returns are fully realized here. In China, three Internet companies have emerged: Baidu, Alibaba and Tencent, most often referred to by the acronym BAT. BAT companies have played a significant role in shaping China's policy to "accelerate the creation and improvement of ICT infrastructure and technology that would directly benefit companies commercially" (To, 2022, p. 108).

State-owned enterprises in China, like those around the world, definitely face challenges in the efficient use of resources. For example, the return on assets fell between 2010 and 2018 for both private and foreign firms (from more than 11% to about 7%), but from 4% to less than 3% for state-owned enterprises (Clay, Atkinson, 2023, p. 66). The difference in the profitability of state-owned enterprises is also because they often perform strategic functions in the economy and are associated with the production of public and quasi-public goods.

China's experience shows that the key to the development of the national innovation system is not only the amount of state funding for R&D, but also the quality of state regulation to create infrastructure and effective mechanisms of market coordination and administrative control.

The institutions governing markets and innovation markets change occasionally to counter various manifestations of social instability: financial risks, social inequality, economic slowdown, or social unrest. Big corporate players like tech giants or regional elites influence changes in rules and institutions, but the stabilizing factor is the Chinese Communist Party, whose policies are the foundation for development and conflict resolution. Although historically associated with the state and state capital, the Chinese government willingly delegates economic freedoms to domestic or even foreign market players if it promotes economic development (To, 2022, pp. 186–187).

National innovation systems in the United Kingdom and United States

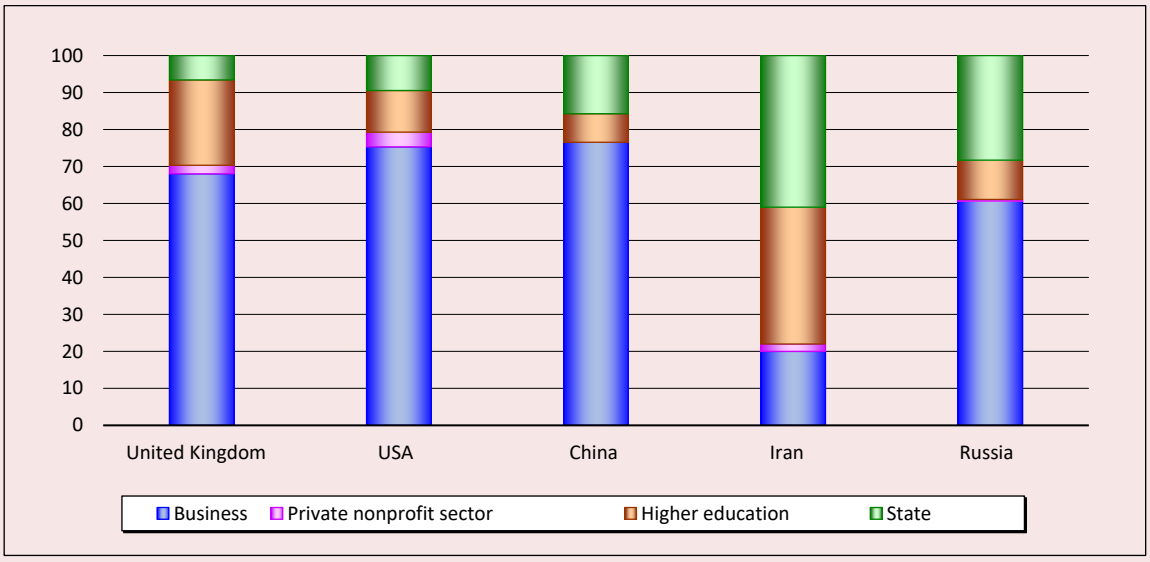
The United Kingdom and the United States of America, on the one hand, are united by their global leadership in various socio-economic aspects, and, on the other hand, by the seeming similarity of their national innovation systems. With incomparably fewer resources, the United Kingdom has to prioritize its innovation policy differently. Table 1 shows that the United Kingdom and the USA have leading positions in various world rankings.

The leadership, including in the Global Innovation Index, objectively confirms the presence in these countries of the necessary three fundamental conditions for their innovative development. For example, political and economic stability in the USA and the United Kingdom, unlike China and Iran, has long been ensured by well-developed democratic institutions, as well as the protection of property rights and the judicial system's independence. And increasing returns to scale are, in turn, ensured, on the one hand, by the availability of technological industries, and on the other hand, by the presence of the necessary demand for innovation through the functioning of the market economy, which promotes entrepreneurial initiative.

In general, we can say that this is due to the presence of political and economic inclusive institutions, i.e., those institutions that facilitate the population's participation in government and best allow them to realize their talents and skills (Acemoglu, Robinson, 2012, p. 89). In the UK and the USA, unlike in China, these institutions have been formed by locating them in a "narrow corridor", i.e., a corridor of balance between the state's power and the society that controls it (Acemoglu, Robinson, 2021). When applied to the USA innovation system, the actual fulfillment of the above fundamental conditions for the country's innovative development is called the "innovation success triangle" – success in business, innovation environment and regulation (Atkinson, 2014, p. 2).

Business and academia are central actors in the British and American innovation systems. The combined contribution of these two actors to R&D spending is 91.10% in the UK and 86.57% in the USA *(Fig. 1)*. The leading role of business is related to the widespread view of innovation regulation in these countries, which is that business is better at allocating R&D investments than government (Melaas, Zhang, 2016, p. 4). International rankings confirm the leading roles of British and American higher education globally. There are 5 American and 4 British universities in the top ten of the world's leading universities according to QS (QS World University Rankings 2023) or 7 American and 3 British universities according to The Times (The Times Higher Education World University Rankings 2023)[7]. In addition, it is worth noting

Figure 1. Share of sectors in the structure of R&D expenditures, %



Source: Eurostat and UNCTAD*.

* For the United States and China, we used Eurostat data for 2020; for the United Kingdom and Russia, only 2019 data are available. The most relevant data for Iran are from the 2016 UNCTAD report. The "Private and non-profit sector" column provides information on "Private and non-profit sector expenditure on R&D".

[7] By comparison, the best Chinese university is ranked 12th by QS (Peking University) and 16th by The Times (Tsinghua University). Among Russian universities, Moscow State University has the highest place (75 and 163 places in the rankings, respectively). Sharif University of Technology in Tehran ranks 380th according to QS, and the positions of Iranian universities according to The Times rankings start only from 350–400th place.

that the Academy's share of UK R&D expenditures exceeds 23%, which is about twice that of the U.S., or three times that of China.

The UK's rich scientific tradition is combined with effective science management (Liu et al., 2015, p. 328). The UK Research and Innovation (UKRI), a specialized body sponsored by the Department for Science, Innovation and Technology, was established in 2018 to develop and manage the NIS. Bodies such as UKRI play a vital role in the success of public innovation policy because they "pool expertise, organize innovation processes, and serve as links between sectors and levels of activity" (Breitinger et al., 2021, p. 8).

We should emphasize that the UK NIS is historically linked to the macro-European innovation system due to the country's geographical location and economic integration within the European community. The British NIS is characterized by an extremely high degree of internationalization, which was one of the highest among all members of the European Union before Brexit (Hughes, 2012, p. 48; Weresa, 2018, p. 20).

Naturally, Brexit itself and its consequences, still not entirely predictable (Breitinger et al., 2021, p. 58), are a challenge for the future. Before Brexit, Britain was heavily reliant on sources of research funding from European funds, which, on the one hand, provided stability through long-term research projects and, on the other hand, formed synergies in combination with domestic funding sources (Weresa, 2018, p. 37). For example, whereas previously Oxford and Cambridge Universities jointly received funding from European research programs of 130 million euro annually, this amount has now been reduced to 1 million euro[8].

In addition, the United States spends about twice as much money on R&D (as a percentage of GDP) as the United Kingdom *(Fig. 2)*. Moreover, compared to the 2000s, the United Kingdom's share of this expenditure in GDP has increased by only 10%, while the percentage of the United States has increased by 38, Iran's share has increased by 76%, and China's share has increased by 238%.

It is evident that lagging behind the U.S. and China in gross expenditure on R&D is a challenge for the British NIS, so the UKRI Strategy 2022–2027 sets out plans to increase this figure to 2.4% by 2027[9], which acts as a priority for the fourth strategic objective "World Class Innovation".

Reaching the 2.4% of GDP figure in R&D expenditure is planned in close cooperation with private businesses, as emphasized several times in Strategy 2022–2027. For example, for every pound of grant funding Innovate UK will receive 13 euro of venture capital investment in the future. As an example of attracting private investment, the UK Research Partnership Investment Fund, which supports investment in British universities for every pound it has, also uses 2 euro from nongovernment funding sources. Based on Strategy 2022— 2027, the UKRI Corporate Plan 2022— 2025 was adopted, which includes a specific list of actions and a set of targets for the coming years.

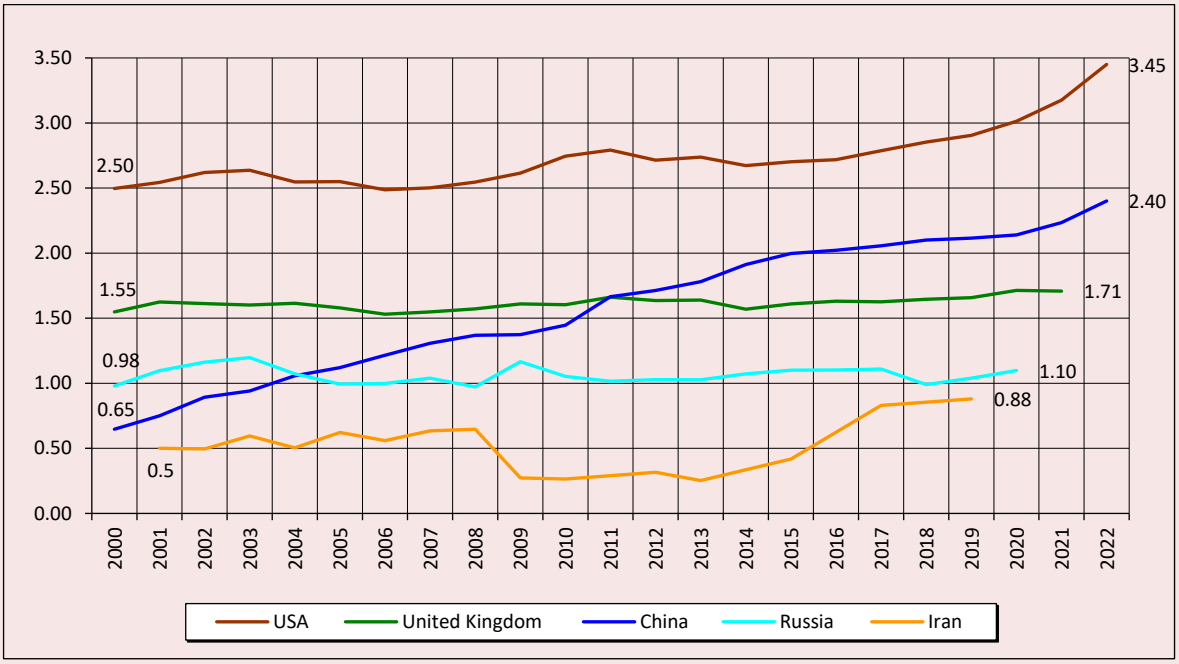
Having analyzed Strategy 2022–2027 and Corporate Plan UKRI 2022–2025, we can conclude that the main task in the UK is to create the necessary institutional environment for the development of the national innovation system, the

[8] Brexit causes collapse in European research funding for Oxbridge. The Guardian. February 4, 2023. Available at: https://www.theguardian.com/education/2023/feb/04/brexit-causes-collapse-in-european-research-funding-for-oxbridge-universities (accessed: June 2, 2023).

[9] UKRI Strategy 2022–2027. Available at: https://www.ukri.org/wp-content/uploads/2022/03/UKRI-210422-Strategy2022To2027TransformingTomorrowTogether.pdf (accessed: June 2, 2023).

[10] UKRI Corporate Plan 2022–2025. Available at: https://www.ukri.org/wp-content/uploads/2022/08/UKRI-190822-CorporatePlan2022to2025.pdf (accessed: June 2, 2023).

Figure 2. Total spending on R&D, % of GDP



Source: OECD and World Bank

development of human capital (for example, attracting highly qualified specialists, creating conditions for the appearance of jobs for such specialists), as well as attracting private investment in the innovation sphere; it means that this approach can be characterized as a market approach to innovation regulation.

In addition, researchers (Breitinger et al., 2021, p. 57; Lampel et al., 2020, p. 105) note the important role in the development of the British NIS of the non-profit body Nesta (formerly, it is called the National Endowment for Science, Technology and the Arts). Nesta conducts basic, applied research to promote UK innovation and implements practical innovation programs. Some of these programs combine funding from Nesta and other sources (Bakhshi, Flew, 2018).

In contrast to the United Kingdom, due to the truly federal structure of the state, the U.S. innovation system is decentralized (Shapira, Youtie, 2010, p. 5). Nevertheless, the National Science and Technology Council plays a significant role in the NIS development by the federal government, which specializes in consulting and helping to develop and evaluate public policy in relevant areas (Kang et al., 2019, p. 9). This council belongs to the cabinet level, and its status, for example, is underlined by the fact that it comprises the vice president and the director of the Office of Science and Technology Policy. In 2023, the National Science and Technology Council released a report on the role of artificial intelligence in science and technology policy "Strengthening and Democratizing the U.S. Artificial Intelligence Innovation Ecosystem[11], in which Artificial Intelligence is seen as a driver of innovation.

[11] Available at: https://www.ai.gov/wp-content/uploads/2023/01/NAIRR-TF-Final-Report-2023.pdf (accessed: June 2, 2023).

Innovation occupies an important place in the National Security Strategy[12], adopted by the White House in 2022, which notes that "while the private sector and open markets are a key driver of American innovation, strategic public investment is the foundation of a strong industrial and innovative base of the global economy of the 21st century. In 2021, the United States also passed The United States Innovation and Competition Act (in 2022 it became part of the CHIPS and Science Act) [13] , which plans to spend about 250 billion US dollars on innovation by 2026, namely on semiconductor manufacturing, scientific research, artificial intelligence development and space exploration[14] in competition with China as the main rival to the U.S. on the world stage.

The U.S. global leadership in innovation is also confirmed by the Global Intangible Finance Tracker 2022, according to which 9 of the 10 most expensive brands in the world belong to the U.S. national innovation system, with the most expensive "Chinese" brand in 34th place and the "British" brand in 37th.

Nevertheless, despite U.S. leadership in this and other rankings, some scholars suggest that the U.S. NIS faces particular challenges due to slowing productivity growth in innovation-driven sectors[15]. Ignoring these challenges could allow China to overtake global leadership in innovation.

Iran's national innovation system

Studying the evolution of the national innovation system of Iran is connected with the difficulties caused by the language barrier, unreliable statistics and the relative closedness of the Internet space to the outside observer. Also, the study of the NIS structure faces limitations due to the features of the distribution of power and the Iran's internal political structure. Even the institutional structure of the Iranian NIS can be described in several ways. Goodarzi, Rezaalizadeh, and Gharibi propose a hierarchical scheme for the NIS organization (*Fig. 3*), subordinated to the Supreme Leader of Iran, Ali Khamenei, who combines the supreme political and religious power (Goodarzi et al., 2017).

The hierarchical structure does not reflect the political complexities and real governing functions of ministries and agencies in Iran, so the work of several researchers (Heshmati, Dibaji, 2019; Afshari-Mofrad et al., 2020) and a new report by the Iran Institute for Technology and Innovation Development[16] suggest that Iran's NIS should be viewed as a multi-level system of multiple subordination with complex informal ties.

The zero level is responsible for shaping strategy and defining strategic goals at the state level, on the basis of which science and technology policy is determined. These are the Supreme Council for Science, Research and Technology, the Supreme Council for the Cultural Revolution, and the Expediency Council.

The first level includes the organizations that develop science and technology policies and are responsible for their implementation and

[12] Available at: https://www.whitehouse.gov/wp-content/uploads/2022/11/8-November-Combined-PDF-for-Upload.pdf (accessed: June 2, 2023).

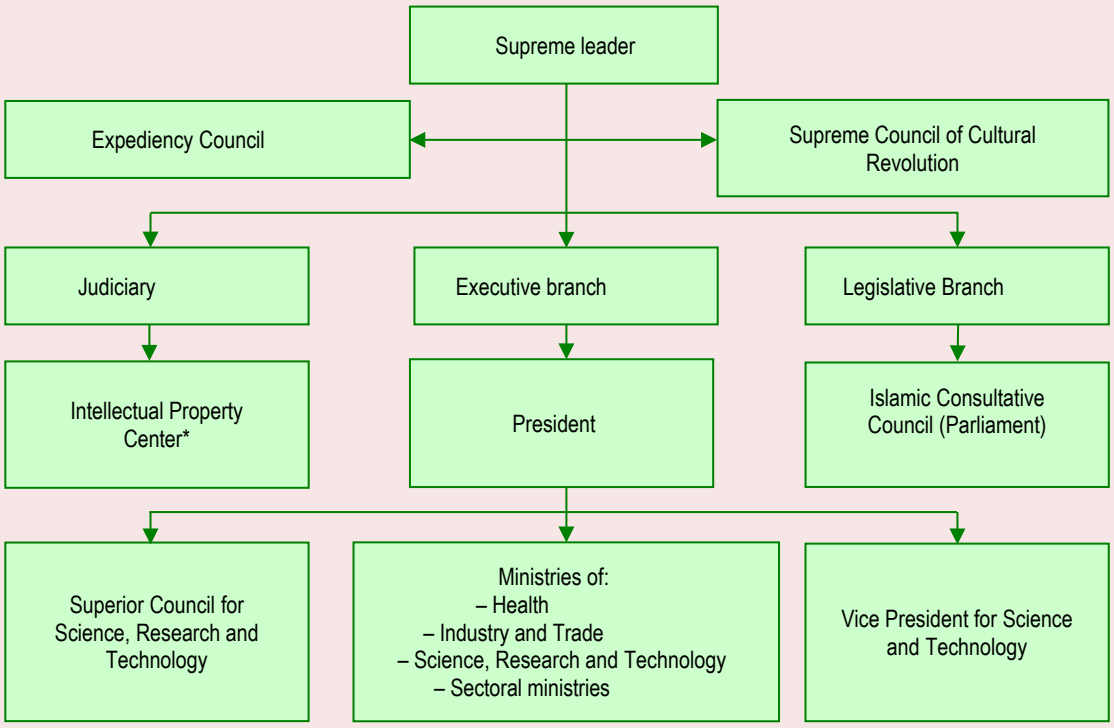
[13] Available at: https://www.congress.gov/bill/117th-congress/senate-bill/1260 (accessed: June 2, 2023).

[14] The U.S. Innovation and Competition Act: Senate Passes Sweeping $250 Billion Bill to Bolster Scientific Innovation and Compete with China. Sidley, July 16, 2021. Available at: https://www.sidley.com/en/insights/newsupdates/2021/06/an-overview-of-the-united-states-innovation-and-competition-act. (accessed: June 2, 2023).

[15] Why the U.S. Innovation Ecosystem Is Slowing Down. Harvard Business Review, November 29, 2019. Available at: https://hbr.org/2019/11/why-the-u-s-innovation-ecosystem-is-slowing-down (accessed: June 2, 2023).

[16] Iranian Technology and Innovation Development Institute (2023). Science and Technology in Iran: a Brief Review 2023. Tehran. Available at: https://rome.mfa.gov.ir/en/newsview/710019/sciencetechnology-and-innovation-in-iran-a-brief-review-iran2023 (accessed: June 2, 2023).

Figure 3. Institutional Map of Iran's NIS (hierarchical approach)



* Iran' feature can be considered the fact that the Intellectual Property Center falls under the jurisdiction of the judiciary, not the executive branch, as in other countries.

According to: Iranian Technology and Innovation Development Institute (2019). Science and Technology in Iran: a Brief Review 2019. Tehran; (Goodarzi et al., 2017, p. 16).

monitoring. The key ones are the Ministry of Science, Research and Technology (which regulates all universities in Iran, except medical universities) and the Ministry of Health and Medical Education (responsible for all medical colleges and universities).

The second level is represented by the institutions responsible for financing and distri buting the budget for science and education. The central organization at this level is the Plan and Budget Organization, which reports directly to the presi-dent. It also includes a variety of foundations, most of which are funded from the budget, but private foundations provide venture capital or startup support.

The third level includes organizations directly responsible for research and development: universities, research centers, and innovative enterprises.

Representatives of several foreign research organizations have noted the special role of the Islamic Revolutionary Guard Corps (IRGC) and the Ministry of Information of the Islamic Republic of Iran ideveloping cybersecurity-related technologies. According to the report, these organizations have concentrated development in this area, allowing them to achieve meaningful technological solutions despite their lack of access to advanced hardware and software products (Anderson, Sadjadpour, 2018).

Although Iran had long been under economic sanctions[17], it was only in 2004 that the U.S. Treasury Department imposed measures against scientific activities. In fact, this was the first time the USA equated publishing and reviewing scientific papers from Iran to circumvent the embargo (Brumfiel, 2004). Further, from 2006 to 2010, the UN Security Council passed six resolutions against Iran's nuclear program, severely affecting the country's economy. For instance, leading universities and research institutes were effectively denied access to scientific databases. Iranian academic institutions faced bans on procurement of high-tech equipment, including computer hardware, for fear that it could be used to pursue a nuclear program. In addition, Iranian Internet users often face IP address blocking, which prevents them from using a number of research tools and foreign software products.

The main damage that sanctions do to the NIS is to create barriers to technology transfer. First, there is a ban on the purchase of technology from high-tech firms – technology cannot be bought. Second, restrictions are imposed on commercial activities with a sub-sanctioned country – it is impossible to buy high-tech goods[18]. And third, obstacles are created for academic institutions and scientists – the process of creating new knowledge and technologies and technology transfer using their own technological base becomes more complicated, which leads to scientific and technological lagging and, consequently, to a decrease in domestic economic and political stability (Fakhari, 2017).

Despite this, in 2010 Iran was among the leading countries in terms of the growth rate of scientific publications. Today, Iran is ranked 21st in the Scopus citation database by the number of articles and 29th by the number of citations, slightly behind Turkey (20th and 27th, respectively). At the same time, Turkey is not subject to measures to restrict publication activity. And in 2015, Iran ranked among the top five engineering graduates[19] (Heshmati, Dibaji, 2019).

The main reason for the growth is demographic. Iran's fertility rate has fallen below two children per woman, but the population is growing due to increased life expectancy, with only about 7.7% of the elderly population. The mentioned demographic trends are competently used by the government policy, which was carried out in three directions: increasing access to higher education (1990–2010); defining priority areas of research (since 2010); developing a mechanism for the transfer of innovation for the transition to a knowledge-based economy (since 2015).

The management model of the innovation system is based on policy documents. The main one was issued back in 2005 – it was the "Vision 2025" strategy[20]. The Supreme Leader proclaimed the updated key goals of the national policy on science and technology in September 2014. These included improving the NIS to increase

[17] The starting point can be considered 1951, when Prime Minister M. Mossaddegh announced the nationalization of the Anglo-Persian Oil Company. This was followed by an embargo on Iranian oil products by Britain and the United States, which led to the overthrow of the democratically elected Mossaddegh government in 1953 with the direct involvement of the intelligence services of those countries. Due to the unresolved Anglo-American contradictions in the Middle East, a similar method was used in 1979 against Shah M.R. Pahlavi (Axworthy, 2013; Smirnov, 2020).

[18] In addition, it exacerbates the bottle-neck problem of Iran's NIS: the low level of private sector participation in the science and education system. Isolation from the global market limits the ability to scale innovation and, as a consequence, leads to greater government involvement in innovation (Abdi et al., 2014).

[19] See also: World Economic Forum (2015). The Human Capital Report 2015. Available at: https://www.weforum.org/reports/human-capital-report-2015/ (accessed: June 2, 2023).

[20] 20-Year national vision. Available at: https://irandataportal.syr.edu/20-year-national-vision (accessed: June 2, 2023).

the share of knowledge-based products, as well as bringing spending on higher education and research and development to 4% of GDP. By 2019, this spending exceeded only 2% of GDP[21]. In general, Iran has maintained higher education spending at 1–1.2% of GDP, which has led to an increase in the number of persons with higher education and, most importantly, an increase in the number of researchers.

Large number of young people demanding higher education, coupled with an active educational policy, allows Iran to cope with the challenges of sanctions and create its own science and engineering schools. While in 1953 Iran had only four universities with 14,500 students, by 1977 there were 16 with 154,000 students. The Islamic Revolution did not stop the development of higher education, but contributed to the continuation of the trend of increasing the availability of education[22]. The active establishment of universities and research centers has increased the number of students from 1.5 million to 3.1 million between 2000 and 2021 (49.2% women, 50.8% men)[23]. More than 260,000 people are trained in PhD programs[24]. The total number of universities in the country is 1102, of which 57 are under the Ministry of Health, 149 are affiliated with the Ministry of Science, Research and Technology, 329 are private universities and 567 are affiliated with the Islamic Azad University[25]; and there are 686 research centers, of which 356 are attached to universities and 233 are private research institutes.

Despite all the sanctions, Iran has managed to build a distinctive national innovation system, leading among Central and South Asian countries (it gives in only to India) and among lower-middle-income countries (it gives in only to India and Vietnam) in terms of the innovation development index. Iran has the ability to independently develop or borrow critical technologies from various sources, taking advantage of its favorable geographical location, oil revenues, and the growing level of education of its population.

Conclusion

We have studied the national innovation systems of four countries: China, the United Kingdom, the USA and Iran. If the USA and the United Kingdom are characterized by a stable and developed NIS with a long history, Iran and China can be classified as developing innovation systems, although they demonstrate significant success.

One of the main prerequisites for the development of innovation systems in Iran and China can be considered a truly long-term higher education policy, which, combined with population growth, has led to a significant increase in access to higher education. Under such conditions, creating one's own science and engineering schools is inevitable. Education and science play a significant role in national innovation policy in the USA and the United Kingdom. On the one hand, this is confirmed by the dominance of British and American universities in world rankings,

[21] If we consider that higher education accounts for about 1/3 of total education spending, then together with R&D spending, the figure would be 2.08% of GDP.

[22] Average years of schooling increased from 4.2 years in 1990 to 10 years in 2010.

[23] According to: Iranian Technology and Innovation Development Institute (2019). Science and Technology in Iran: A Brief Review 2019. Tehran. Available at: http://en.cpdi.ir/uploads/1/2021/Nov/22/Science%20and%20Technology%20in%20Iran-A%20brief%20review%202019.pdf (accessed: June 2, 2023).

[24] But we should remember about the brain drain problem in Iran: an average of 63,000 people a year (mostly with high levels of human capital) immigrate to the United States (32%), Canada (14%), Germany (11%), the Netherlands (6%), Sweden (5%) and Turkey (5%) (Azadi et al., 2020).

[25] Islamic Azad University is a private university with an extensive network of branches, one of the largest universities in the world with more than 1 million students in 2022 (annually enrolls about 320 thousand students at various levels, including 10 thousand for PhD programs).

and on the other hand, by the understanding of the need to invest in R&D (in the USA this indicator is more than 1.4 times higher than in China; the UK plans to increase its indicator by 40% by 2027 compared with 2020). It confirms the importance of the *premise related to education and science* for the sustainable development of the NIS.

An equally important factor is the focus on the development of market infrastructure. However, there is a discrepancy between the experience of China and Iran. Due to the smaller size of the domestic market and limited access to the international market, Iran is forced to pursue a more centralized innovation policy to solve key economic and military-political problems. At the same time, China, due to its access to advanced technologies and global markets, was able to use a market-oriented mechanism to create an innovation system that not only competes on an equal footing with innovation systems of the West, but also poses a threat to them, moving from copying to developing its own innovative technologies.

Success in developing market infra-structure is directly related to mechanisms of increasing returns, which are fully used by the USA, the UK and China, integrated into the still global system of division of labor. Iran's opportunities here are severely limited; they face serious sanctioning opposition from Western countries.

Iran's NIS is just at the initial stage of forming an entrepreneurial initiative in the field of innovation mainly due to the sanctions policy against the republic, which significantly increases the costs associated with innovation activities. In contrast, the innovation systems of China, the USA and the United Kingdom can be considered far ahead on this criterion.

Still, the main difference between the innovative systems under consideration lies in the way of achieving political and economic stability. Whereas in the United States and Britain stability is achieved through strong democratic institutions, as well as the protection of property rights and the independence of the judiciary, China achieves stability through the leadership of the Communist Party, balancing the interests of large entrepreneurs, elite groups and the general population by legitimizing its efforts with economic success. Describing the mechanisms contributing to Iran's relative stability is the most challenging task, as it implies considering cultural and religious values combined with the intertwining of divergent national interests.

The combination of institutions that promote political stability and the development of a market economy is necessary for developing the NIS. The obtained conclusions of the study, including our identified prerequisites for the NIS development in the four countries, make us think about how the Russian innovation system is developing. Further research in this area can be directed to the development of specific recommendations in the sphere of domestic innovation policy, including those based on the world's best practices.

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Received April 24, 2023.