China on the Way to Global Technology Leadership

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Abstract—China’s science and technology complex is considered with account for the dynamics of its development and the structure that has developed to date. Particular attention is paid to the areas that are viewed as the most promising in the course of the fourth industrial revolution; the situation in these technological areas is compared with that in the United States. In addition, the situation in the field of intellectual property in China is analyzed: it is shown how the country has transformed from the main “violator” of intellectual rights into a significant player in the global market of new technologies. The problems that China faces along this path, including the phenomenon of “junk” patents, are highlighted. The prospect of creating a relatively independent technological circuit in China is assessed in the light of the general strategy proclaimed in 2021 to rely mainly on internal factors of growth and development.

Keywords: science and technology complex, technological rivalry, artificial intelligence, Internet companies, semiconductors, intellectual property, junk patents

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At the end of the second decade of the 21st century, having quickly and successfully overcome the economic downturn caused by tough antiepidemic measures, China continued its progressive economic development. An integral part of the country’s steady progress is its scientific and technological revolution, which has affected almost all aspects of the life of the giant state. Based on its achievements, China completed the transition to an intensive economic development model during the 13th Five-Year Plan (2016–2020) and posed new ambitious tasks for the short and medium term (up to 2035) at the turn of the decade.

Back at the beginning of the second decade of the 21st century, China’s economic and technological achievements, foreign economic expansion, and independent international course caused a negative reaction from the United States and the first forecasts of a significant deterioration in relations between the two powers [1]. In the middle of that decade, a sensational monograph by the veteran expert in international relations G. Allison was published, in which “Thucydides’s trap” symbolized possible confrontation between the United States and China, that is, a situation dangerous for the world when a new world leader is replacing the old global hegemon (like Athens in Ancient Greece, opposing the dominance of Sparta, which led to the Peloponnesian Wars) [2].

As is known, it was the foreign economic sphere that became a practical embodiment of the negative attitude towards China during the years of D. Trump’s rule. During that period, in the context of US–China relations, the phrase trade war became popular, although it would be more correct to call this phenomenon US trade aggression since the Chinese side demonstrated a constant readiness for compromise. The same is true regarding the technological sphere, although, in relation to China, which was taking only limited measures in response to Washington’s acts of technological aggression, the word war is not entirely accurate [3]. The word rivalry seems to be more correct to define the relations between the parties in the trade and technological sphere, since we are considering long-term processes, and acts of aggression by the US establishment coexist with the continuation of close and versatile interaction between the businesses of both countries [4]. American companies make a significant contribution to China’s high-tech manufacturing (and exports). Note that the parameters here
are gigantic: in 2020, China produced 250 million computers, 25 million cars, and 1.5 billion smartphones [5].

A WORTHY RIVAL

Comparison of the technological potentials of China and the United States is a quite appropriate methodological technique today for assessing Chinese positions in the global technosphere. In particular, it was used in a report of the Harvard Kennedy School with Allison as the lead author. The report was released in December 2021 and is a thorough examination of the common positions of the United States and China in several technological areas, which the authors consider fundamental in the 21st century [6]. These are, in particular, artificial intelligence (AI), the fifth generation of mobile communications (5G), quantum communication and information processing, semiconductors (integrated circuits), biotechnology, and green energy. In the preface to the report, the authors, referring to E. Schmidt (long-time head of Google), declare their concern that China seeks to deprive the United States of superiority in new technologies, and soon “we will be competing with a country that has a bigger economy, more research and development investments, better research, wider deployment of new technologies, and stronger computing infrastructure” [6, p. V]. Note that Xi Jinping also points to the importance of technological competition: according to him, “Scientific and technological innovation has become the main battlefield of the international strategic game, and the competition around the commanding heights of science and technology is unprecedentedly fierce” [7].

In several areas of AI use, China has already surpassed the United States. In particular, this includes speech recognition technologies, where Chinese companies are ahead of US firms in all languages, including English. China’s iFlytek, for example, has 700 million users, doubling Apple’s Siri. The situation is even more clear in the field of financial technologies: WeChat Pay has 900 million users and is an order of magnitude ahead of Apple Pay with its 44 million customers. In face recognition, Chinese companies are unrivaled. SenseTime and Megvii have developed apps that make it possible to identify anyone within seconds in a country with a population of over 1.4 billion people.

Chinese Internet companies are rapidly strengthening their positions in the global market. Six years ago, only two Chinese companies were among the top twenty global Internet giants. At present, Baidu, Alibaba, and Tencent have joined Google, Amazon, Facebook, and Microsoft to form the top seven in this field. Of every ten dollars invested in AI venture capital in 2018, five came from China and four from the United States. Among the world’s most valuable AI start-ups, seven are American and three are Chinese. In one of the most important areas of development of artificial intelligence, deep learning, China has six times more published patent applications than the United States. According to some forecasts, by 2025 the United States will yield to China the palm in 1% of the most cited articles on AI [6, pp. 2, 6].

Finally, it is worth mentioning the use of industrial robots in China. Their number in 2020 reached 140,000, which was more than in Japan, the United States, South Korea, and Germany taken together [8, p. 14]. Impressive are fully automated warehouses (automation of the largest container port in Shanghai is on the agenda), unmanned taxis in some Chinese cities, and plans to organize smart cities. According to Schmidt, in AI technologies, which will have an exceptionally high impact on the economy and security in the near future, “China is now a full-spectrum peer competitor” of the United States [6, p. III]. As the National Security Commission on Artificial Intelligence assessed, “China possesses the might, talent, and ambition to surpass the United States as the world’s leader ... if current trends do not change” [6, pp. 3, 4, 9].

Speaking about the two countries’ race in the field of AI and the technological competition in general, we should bear in mind that Chinese universities graduate four times more bachelors with STEM1 specializations, and by 2025 they will train twice as many PhDs with this specialization. One can agree with the opinion of T. Chhabra, Director for Technology and National Security of the US National Security Council, that the United States is no longer the world hegemon in science and technology.

An area where China already has a clear advantage over the United States is 5G communications. By the end of 2020, there were 150 million users of this standard in China compared to 6 million in America; by that time, 700,000 base stations had been deployed in China compared to 50,000 in the United States. In China, the stations provided a data transfer rate of 300 Mbps, while in the United States, it was only 60 Mbps. In total, at the end of 2020, China accounted for 87% of all global 5G connections. China is also leading in the development of the next generation of mobile communications, accounting for 35% of international 6G patents versus 18% for the United States. There are two Chinese companies in the list of the top five 5G equipment manufacturers, with Huawei topping the list with a 28 percent share of global sales. There are no American companies on this list any longer, while even relatively recently, in 2000, Lucent and Motorola accounted for 25% of the world’s sales of equipment for mobile communications.

In the field of quantum technologies, the United States had been the undisputed leader for a long time, but by the end of the 2010s, the situation changed: China outstripped the United States in quantum com-

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1 STEM stands for science, technology, engineering, mathematics.
munications and is rapidly closing the gap in quantum computing [4; 6, p. 4]. Thus, in December 2020, a year after Google’s 53-qubit Sycamore quantum computer reached the so-called quantum supremacy, the research team of the University of Science and Technology, located in Hefei and headed by Pan Jianwei, managed to surpass this milestone and six months later set a new record on the Zuchongzhi quantum computer. Pan Jianwei, dubbed China’s “father of quantum,” put it very clearly: “We were only a follower and a learner at the birth of modern information science. Now we have a chance … to be the leader” [6, p. 14].

The superiority of China in the field of quantum communications—the “gold standard” of security—is clearly visible in patent activity: in 2018, China registered over four times more patents than the United States in quantum security and cryptography (517 to 117). China has developed systems for quantum communication between satellites and a ground station at a distance of over 800 km, as well as the first integrated quantum communication network on the planet for a total distance of over 3000 km. Looking to the future, we can say that China is closer than others to the creation of a quantum Internet. The latter, M.E. Sokolova notes, is “practically unhackable and will greatly speed up the exchange of huge amounts of data and become an important technological breakthrough. Even at the initial stage of its creation, this will have a profound impact on science, industry, and national security, and primarily on medicine, the banking sector, and mobile communications” [4].

Although the United States still leads in biotechnology (in particular, it accounts for seven of the ten largest life science companies in the world), China has launched intensive R&D across biotechnology. The efforts are paying off: the Chinese have significantly narrowed the gap to the United States in CRISPR gene-editing technologies and have surpassed the Americans in CAR T-cell therapy. An important detail is that genome sequencing costs $100 in China, which is six times less than in the United States. In the decade 2007–2017, the number of Chinese publications on biotechnology increased by 20% annually. In 2019–2020, China surpassed the quality of German and British publications (the Nature index). In terms of the number of patents in biotechnology, China increased its share in the world from 1% in 2000 to 28% in 2019. The share of the United States during that period decreased from 45 to 27%. China is rapidly increasing its share of the global biopharmaceutical market; over the past decade, it has grown from 7 to 22%. In addition, China accounts for 40% of the world production of active pharmaceutical ingredients [6, pp. 22, 23]. The largest number of people on the planet have been vaccinated with the Chinese vaccines Sinopharm and Sinovac against COVID-19.

The situation when China is rapidly reducing the gap to the leaders has also developed in the field of semiconductors (integrated circuits), where the United States remained the world leader for almost half a century, although it was losing its positions, from 37% in 1990, its share in the manufacture of microchips decreased to 12% in 2020 (the leading manufacturer is now Taiwan, about 50% of the world sales). At the same time, the efforts made by China in this area make it possible to conclude that in the near future it will significantly strengthen its position in two areas—the design of microcircuits and their manufacture. At present, it accounts for 15% of world production against 1% in 1990. However, it is difficult to make predictions in this field: in addition to the United States, Taiwan, and China, there are several other strong players in it—South Korea, Japan, and the Netherlands. According to some estimates, in the coming decade, China will account for 40% of the growth in world microchip production, and it will become the world leader with a 24% share in production [6, p. 22].

Thus far, China remains the largest net importer of integrated circuits, which strengthens its desire for self-sufficiency. In particular, the country buys 36% of the chips made in the United States. The United States and South Korea have also recently made large financial injections into the industry. It is possible that the shortage of microcircuits in the world market, which appeared in 2021, will soon be replaced by their overproduction.

China’s breakthrough in the field of green energy is impressive. From 1% of the output of solar panels in 2000, the country increased its output to 70% of world production (the US share decreased from 30 to 1% over the same period). Four of the ten largest manufacturers of wind turbines are Chinese, accounting for 40% of global output (the US share here is 12%). China has a close to exclusive or leading position in many components to produce solar panels, batteries, and other equipment for green energy, including lithium (50% of world output), polysilicon (60%), rare earth elements (90%), natural graphite (70%), and refined cobalt (80%) [6, p. 32].

Note that in addition to the above-described branches of the technosphere, in which the rivalry between the two states develops with a preponderance of one side or another, some facts can be cited that indicate the general prerequisites for a further change in the balance of power in favor of China. This is the above-mentioned superiority in the number of graduates of natural-science and engineering faculties (1.3 million per year in China against 300000 in the United States). At the same time, China graduates 185000 ICT specialists against 65000 in the United States. Of every ten people who receive a PhD in ICT in the United States, only three are Americans, while two are Chinese. Importantly, 30 years ago, only one of 20 Chinese students sent abroad returned home after graduation, while now the ratio is four to five.

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INTELLECTUAL PROPERTY AS A FACTOR OF TECHNICAL ACHIEVEMENTS

A necessary condition for innovative growth and reaching the maximum possible self-sufficiency in technologies, which is very important for China due to the hostile policy of the West in the technosphere, is close attention to issues of intellectual property in its diverse aspects. Undoubtedly, a comfortable legal framework is required: rights to developments must be recognized in law and protected, transactions with these rights must be clearly regulated, and sanctions must be imposed for the consequences of their violations. A significant factor is the timely updating of legislation: delays in legal regulation in today’s dynamically changing conditions happen rather often; they are also typical of the scientific and technological sphere where new objects are created for which the existing legal regimes are often inapplicable. Law enforcement practice is no less important because the merits of even the most developed legislation are easily leveled by its nonobservance. Finally, there is nothing to talk about in the absence of intellectual property as such—in-demand innovative developments, technical solutions, well-known brands.

China, although not always flawlessly, is working in all the areas mentioned above. In lawmaking, an important step was the entry into force of the Civil Code of China on January 1, 2021, which is the first codified act adopted since the formation of the People’s Republic of China in 1949 [10]. Provisions on intellectual property in China were not codified, unlike, for example, in Russia, where they are envisaged in Part IV of the Civil Code. In China, individual laws on various objects of protection continue to operate; the Civil Code establishes basic provisions, which recognize the existence of intellectual rights to protected objects, define the very notion of intellectual rights, and consolidate the general principles of exclusive right circulation. In accordance with Article 123 of the Civil Code of China, the list of objects with respect to which an exclusive right is recognized is not closed. In addition to the seven positions named in the code, in cases provided for by law, an exclusive right may be recognized in relation to other objects. Consequently, the possibility of adopting a law on some new protected object, with respect to which an exclusive right is recognized, is allowed. The seven positions already mentioned in the Civil Code include works; inventions, useful models, and industrial designs; trademarks; geographical indications; production secrets; topology of integrated circuits; and new plant varieties. Thus, we are talking about nine protected objects in respect of which an exclusive right is recognized—the right of intellectual property.

Although China has individual laws in relation to various objects of intellectual property, the adoption of a codified act in the field of civil law is an important step in terms of ensuring the legal conditions for the protection and circulation of intellectual property. Indeed, in excluding the features determined by the intangible nature of the results of intellectual activity and means of individualization, they are subject to the general laws of civil law, including the rules on the obligations of the parties.

No matter how significant the legal conditions that ensure the protection and circulation of rights to the results of intellectual activity are, the most important condition for technological security is obviously the availability of innovative developments themselves. China is working hard to solve this problem. China has been the world leader in the number of applications for patents for inventions filed by residents of the country for several years. In 2020, their number was 1,441,085, which is 8.5% more than in 2019. The United States ranks second, more than two times behind China: American applicants filed 495,883 applications for inventions in 2020 [11, p. 34]. Note that the number of applications for a patent for invention filed in the world in 2020 totaled 3,276,700 [11, p. 7]. Thus, Chinese applicants provided about 44% of the global flow. However, there is also a fly in the ointment: a significant part of all Chinese applications is filed with the national Patent Office, where duty rates are low and, expectedly, there is a more loyal approach to examination than abroad. In addition, a significant proportion of applications falls on scientific institutions and universities, for which obtaining patents is a prerequisite for the allocation of state funding and an indicator of the effectiveness of the work performed [12].

Against this background, the indicators on the number of patent applications filed under the PCT (Patent Cooperation Treaty) procedure, which allow obtaining protection of an invention abroad, appear more informative. Here, China has also retained its leadership for several years: in 2020, the number of PCT applications filed by Chinese inventors amounted to 68,720. The United States ranks second, with a much smaller gap than in the previous indicator, with 59,230 applications [13, p. 26]. Importantly, in terms of the number of PCT applications in China, business representatives, that is, entities interested in patenting competitive developments and applying them in practice, are in the lead: 85.8% of PCT applications originating from China were received from business re presentatives, that is, entities interested in patenting competitive developments and applying them in practice, are in the lead: 85.8% of PCT applications originating from China were received from business re presentatives, that is, entities interested in patenting competitive developments and applying them in practice, are in the lead: 85.8% of PCT applications originating from China were received from
them (for the United States, the respective indicator was 85.6%) [13, p. 29]. It is the Chinese company Huawei Technologies Co., Ltd, that ranks first in the world in terms of the number of PCT applications from representatives of the business community (in 2020, it filed 5464 applications). The best in this indicator among American companies (Qualcomm Incorporated) took only the fifth line of the rating, losing to three other Asian giants—South Korean LG Electronics Inc.; Samsung Electronics Co., Ltd.; and the Japanese Mitsubishi Electric Corporation [13, p. 31].

These figures clearly demonstrate that China is actively creating results that need legal protection. It is also obvious that the leading Chinese companies have infiltrated the global intellectual property market. However, it would be premature to state China’s unconditional success in solving the problem of technological leadership. Having ensured the gross patenting of technical solutions, the Chinese leadership has not yet been able to ensure their quality. Returning to the statistics, we note that only 6.7% of all Chinese applications were filed with foreign patent offices. For comparison, the respective figure for the United States was 45.6%; for Germany, 59.4%; and for Japan, 46.3% [11, p. 15]. Would it be too naive to suggest that the general orientation of Chinese applicants towards the national Patent Office is due to their interest exclusively in the domestic market. What is the real reason?

The active government policy aimed at increasing China’s representation in the global science and technology arena has yielded mixed results. On the one hand, China demonstrated an unprecedented growth in patent activity: from 307573 applications filed by Chinese residents in 2010 [11, p. 52] to 1441085 in 2020. Over ten years, China not only increased its own indicator by 4.5 times but also overtook the United States and Japan, gaining a foothold in the first place in the world ranking by a huge margin. On the other hand, the government’s top-down quantitative indicators of the effectiveness of state-funded scientific research inevitably led to forced patenting for the sake of reporting. Applications are filed not only in relation to advanced promising achievements but also to all technical solutions that formally meet the criteria for patentability.

Thus, only a small part of the patented results has the potential to be in demand on the market, while the rest will be patented for the sake of “putting a tick” in required reporting lines. According to 2020 data, only 8.4% of the results for which patents were registered by Chinese universities and research institutes—the main recipients of budgetary funds for science—were covered by license agreements or agreements on the alienation of exclusive rights for the purpose of their commercial use [12]. Regarding university science, Chinese universities are significantly behind American ones in the commercialization of intellectual property. In 2019, a representative of the Ministry of Education of China voiced estimates according to which the best Chinese universities, having five times more patents than their American competitors, were significantly inferior to them in commercialization: 10% of university patents in China versus 40% in the United States [12].

Although excessive emphasis on the number of titles of protection in evaluating the effectiveness of research activities allowed China to become the world leader in the number of patent applications, this gave rise to a massive phenomenon of “junk” patents—titles of protection to technical solutions that a priori do not have commercial value. Note that the phenomenon of junk research results is typical not only of technical solutions but also of scientific publications. In 2011–2018, China shared the palm with India in terms of junk publication flow (almost 100 000 publications each) [14, p. 192; 15]. Junk publications mean articles in so-called “predatory” journals, which charge the authors fees for publications and neglect the peer-review procedure [16].

The mass flow of articles by Chinese authors in predatory editions and the phenomenon of junk patents are due to the indicators used to evaluate scientific activity. However, this is hardly a sufficient reason for a complete rejection of the use of quantitative indicators, which are taken into account not only in China. They were first used in the United States, where, in the late 1970s, a results-based science funding system was introduced, which then spread to a number of European countries, and then to the whole world. Currently, many countries, including China and the United States, use a wide range of scientometric indicators to determine the amount of funding for university science (true, as a rule, they are used in addition to other criteria) [17, p. 106]. At the same time, the quantitative indicators used to evaluate Chinese researchers obviously need to be adjusted with account for the mass junk results.

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It must be admitted that the use of strict quantitative criteria for scientific activity has borne fruit: China’s global leadership in the number of patent applications draws attention to it as a player in the intellectual property market, increasingly displacing from consciousness the image of a sworn infringer of intellectual rights. The next most important step on the path to technological self-sufficiency is the transition from the number of patents to the quality of technical solutions protected by them. If China is as successful in achieving this goal as in quantitative patent leadership, relations with the United States may reach a perfectly different level.

In China, R&D expenditures are steadily growing: from 2.1% of GDP in 2016, they increased to 2.4% in 2020. At the beginning of this century, they were only
12% of the American indicator, while now they have reached 90% [5: 6, p. 32]. During the years of the 13th Five-Year Plan (2016–2020) alone, R&D spending in China increased by a third, from 1.6 to 2.4 trillion yuan, and the number of people employed in this area increased by a quarter, from 3.9 to 5.2 million man-years [5].

Over the past 20 years, China has caught up with (and overtaken) the United States in the number of international patent applications filed under the PCT: from 0.6% of the global indicator in 2000, this figure jumped to 22% in 2019. In the United States, the opposite pattern was observed: for the same period, the indicator decreased from 42 to 22%. Although China remains a major net importer of services related to intellectual property (their imports amounted to $38 billion in 2020), the exports of such services grew very dynamically—from $1.2 billion in 2016 to $8.6 billion in 2020 [5].

Shifts in economic strategy speak in favor of a high likelihood of accelerated development of China’s technosphere in the coming years. In 2021, the idea of “two circuits”—internal (the main one) and external—was enshrined in party and state documents. It is assumed that technological independence (largely achieved to date) will serve as a support for the internal circuit, which, of course, does not exclude the overseas expansion of high-tech Chinese companies. However, such expansion in recent years has faced discrimination in the West, which was one of the reasons for putting forward the idea of two circuits [9, p. 50]. The situation is different in the Belt and Road countries, many of which see technological cooperation with China as a useful balance to ties with the West. Thus, Senegal decided to stop storing government information on foreign servers (controlled by the United States); as a result, China is creating national servers to allow the African country to achieve digital sovereignty.

The growing contribution to China’s economic development is made by its full-fledged and rapidly strengthening science and technology complex. Western technologies, which for a long time were considered uncontested in Russia, can increasingly be replaced by their counterparts from China. The special attention to basic research at the state level, which is now characteristic of the Celestial Empire, opens space for fruitful and long-term bilateral cooperation between our countries.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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