Artificial Intelligence in the development strategy of contemporary China

Inteligência artificial na estratégia de desenvolvimento da China contemporânea

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RESUMO: Este artigo analisa o papel da Inteligência Artificial dentro da estratégia geral de desenvolvimento econômico da China contemporânea, marcada pela busca por transitar para um modelo menos intensivo em capital e recursos e mais intensivo em conhecimento. As políticas de Ciência, Tecnologia e Inovação chinesas são analisadas, destacando a importância crescente da inovação endógena e o papel da Inteligência Artificial dentro deste contexto. Além disso, o artigo apresenta indicadores que buscam avaliar a atual posição da China em comparação com outros países no cenário internacional, em especial os Estados Unidos, considerando a geração de conhecimento científico, o desenvolvimento tecnológico e o envolvimento do setor empresarial.
PALAVRAS-CHAVE: Inteligência Artificial; China; Política Científica e Tecnológica Chinesa; Política Industrial e Tecnológica na China.

ABSTRACT: This paper analyzes the role of Artificial Intelligence in the broader context of China's development strategy, marked by the quest to move to a less capital and more knowledge-intensive model. Chinese Science, Technology, and Innovation policies are discussed, emphasizing endogenous innovation and Artificial Intelligence's role in this context. Furthermore, some indicators are analyzed to compare China's current position with other countries, particularly the United States, in terms of Artificial Intelligence knowledge generation, technology development, and business involvement.
KEYWORDS: Artificial Intelligence; China; China's Science, Technology, and Innovation; China's Industrial and Technological Policy.
JEL Classification: O33; O31.

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INTRODUCTION

The Chinese rise is undoubtedly one of the most remarkable phenomena in the global economy in the 21st century. Chinese development has continued to demonstrate its tremendous strength and transformation capacity despite various forecasts that it will reach some limits or enter a crisis. After going through an extraordinary structural change, becoming the largest producer and exporter of manufacturing goods in the world and constituting a productive and business system that disputes global leadership in several segments, China has also sought to consolidate itself as a leading country in innovation (Lewin et al., 2016; Naughton, 2021; Zhou et al., 2016).

Analyzing Chinese Science, Technology and Innovation (STI) policies since the last quarter of the 20th century, one will note that its capacity for permanent transformation is one of its main distinguishing features. As Chen and Naughton (2017) and Diegues and Roselino (2023) pointed out, such a transformation stems from the coevolution between the different phases of the Chinese economic development strategy and the changes in the political structure, as well as in the institutional and economic apparatus on which these policies are based.

According to authors who adopt an evolutionary approach to economic catch-up (Lee, 2019; Malerba and Lee, 2021; Malerba and Nelson, 2012), innovation systems comprise businesses and non-business actors and institutions that contribute to learning and capability accumulation. It is the relationships between actors and institutions that shape technological and innovation capabilities over time (Freeman, 1995; Lundvall, 2010). However, the trajectory of technological catching up becomes more complex, as the possibilities of assimilation, imitation and adaptation of technologies from leading countries are completed. The next step involves developing new capabilities to go beyond mere imitation.

As a result of rapid economic growth and foreign technology absorption, China faces a crossroads in its development strategy. Keeping up with leading countries requires mastering innovative capacity. This capacity has also been highlighted as a key element to escape the middle-income trap (Lewin et al., 2016). It is also explicitly at the heart of the National Innovation-Driven Development Strategy announced in 2016 by the Central Committee of the Chinese Communist Party (CCP) and the State Council (CSET, 2019; Fu, Mackern, and Chen, 2021). Furthermore, for other authors (Majerowicz and Medeiros, 2019; Capri, 2020; Kania, 2021), the domain of innovation is at the heart of the rivalry between the United States and China.

A recent chapter in this story is the struggle to enter critical Industry 4.0 technological areas. Among them, one of the most important is Artificial Intelligence (AI). AI's distinctive aspect is the breadth of its fields of application, which can revolutionize a wide range of processes, activities, organizations and business models (OECD, 2019; Schwab, 2016). The National Artificial Intelligence Plan launched by China in 2017 outlined its goal of becoming a leading player in this field. Other countries have also followed suit with their own initiatives.

This paper aims to highlight recent developments in Chinese AI strategy. The main contribution of this paper is to present a broad overview of artificial intelligence's role in China's overall development strategy, while also providing some selected key indicators based on an analysis of recent fast-growing and flourishing literature to assess China's relative position in the global AI development dispute.

Today, China is Brazil's largest trading partner. Also well-known is Brazil's enormous specialization in primary commodities exports to China. Considering this, analysing China's strategy of moving towards more knowledge-intensive sectors is of fundamental importance, since it can strongly influence bilateral relations in the future.

In addition to this introduction, the paper is divided into four other sections. In the first section, STI policies in China are briefly reviewed and the quest to master endogenous innovative capabilities is emphasized as one of the guiding principles of the ongoing contemporary challenges of Chinese development. The second section examines the importance of AI within Chinese strategy to become a leading global innovation power. The third section explores some indicators of the growth and development of AI in China compared to the United States and other countries, such as scientific publications, patents, and investments. The last section is dedicated to final remarks.

1 – STI POLICIES IN CHINA AND THE GROWING IMPORTANCE OF ENDOGENOUS INNOVATION

The period following the 1949 Revolution is marked by the quest to consolidate China as an independent nation, after decades of fragmentation, instability and wars (civilian and against external enemies). Given the troubled external environment and the weaknesses of the material bases from which the newly created People's Republic of China started, this effort meant, on the one hand, guiding resources to the military sector. On the other hand, organizing the foundations of heavy industry and removing restrictions on increasing agricultural productivity (Naughton, 2007).

Scientific and technological development efforts at that time were linked to this challenge. The organization of the Chinese Academy of Sciences (CAS), inspired by the Soviet Union model, was a milestone in this regard. CAS was responsible for carrying out the first National Science and Technology Plan in 1956. Although it listed 582 research projects, the plan became known as "Two Bombs and a Satellite", in reference to the development of the Atomic Bomb, the Hydrogen Bomb and the first Chinese Satellite (McGregor, 2010). These large projects give an idea of both the importance of the development of military technologies and the mobilization around big projects in Science and Technology (ST) in this period of consolidation of the Chinese State.

Efforts around large projects, defined by the CCP as fundamental to Chinese development and sovereignty, involved scientists and engineers from many research institutes, universities, and state-owned companies. In a context where defining clear priorities was fundamental given resource constraints and different challenges on the internal and external front, this form of organization led to important results, with the creation of a quite robust ST structure for a country with a very low level of per capita income at the time (Liu and Lundin, 2007).

However, compared to the advances that occurred in the innovation systems in developed countries and even in other developing countries, the ST system in China had limitations. The transformation of scientific and technological advances into innovative products faced intrinsic barriers in a centrally planned economy, relatively isolated in the international scenario and where typical incentives of market economies for the knowledge transfer from scientific institutions to the business system were non-existent.

China's economic opening in the late 1970s engendered important changes in the structure of ST inherited from the period of planned economy. The signs of change were beginning to appear with the end of the Cultural Revolution. The importance of ST for the development of China was reaffirmed, being one of the pillars of the 'Four Modernizations' defended by Deng Xiaoping (Baark, 2001; Campbell, 2013). However, it was with the reforms towards the market that the changes accelerated and triggered important shifts over the following years.

The increase in international purchases allowed the modernization of research laboratories and production processes in several manufacturing sectors. From the centralized system of the previous period, basically concentrated in public research institutions, the changes in the 1980s moved towards a more competitive one, reducing the allocation of resources directly to the public institutes. The changes also sought to expand their reach to boost the fledgling business sector (Feigenbaum, 1999; Zhou and Liu, 2016).

Another set of changes occurred from the second wave of Chinese reforms carried out in the first half of the 1990s. Liu et al. (2011) emphasize that it was from that period that innovation began to be a specific object of policies, in addition to ST. At the same time, the support mechanisms and the number of initiatives were amplified, including tax, fiscal and financial instruments. It is also important to highlight the process of private business diversification. If in the 1980s, Township and Villages Enterprises (TVE) played an extremely important role in generating added value and industrial employment, the changes in the 1990s gave rise to a more diversified business landscape, with state-owned companies remaining in strategic sectors such as infrastructure and capital-intensive heavy industry, while a broader set of private companies took on a more prominent role (Beck, 2023; Chen and Naughton, 2016).

Foreign Direct Investments gained momentum and China was embraced in the productive fragmentation and manufacturing outsourcing within the global value chains, consolidating itself as a major producer and exporter of manufactured goods. The policy of negotiating access to the local market in exchange for technology transfer initiated in the 1980s gained new impetus in the 1990s. But despite the great success in terms of production and manufacturing exports, in the more knowledge-intensive sectors and activities, the dependence on foreign companies' technology remained.

After two decades of high economic growth, with the consolidation of the Chinese economy as the "world factory", in the early 2000s, debates began in the Chinese central planning institutions on the new conditions for guaranteeing the continuity of a virtuous structural change process. Liu and Cheng (2014) and Zhou and Liu (2016) highlight the growing dissatisfaction with the limited technological transfer and learning that resulted from the rising presence of foreign companies in the productive and foreign trade structure. Then, the perception that foreign technological dependence and the subordinate insertion in global value chains were strong threats to the long-term Chinese development strategy consolidated in the CCP.

The discussions eventually lead to the Medium and Long Term Plan for the Development of Science and Technology (MLP) launched in 2006. The plan's guideline was to circumvent the perceived limits of STI policies and readjust them to the new challenges imposed by the constant changes in the international techno-economic paradigm (Cheung et al., 2016; Zhou and Liu, 2016).

MLP marked the beginning of a series of changes, with the acceleration of plans and projects aimed at promoting innovation at the forefront of China's long-term development instruments. Although quite generic, the MLP highlighted the importance of endogenous innovation and the mobilization of the business system, listing at the same time priority technologies, sectors, and research fields that should be targeted by specific measures, goals and instruments from different support policies.

If the MLP already pointed to greater integration between STI Policy and Industrial Policy, listing priority sectors and technologies in line with major scientific projects, the global financial crisis accelerated this integration, with the launch in 2010 of the Strategic Emerging Industries (SEI) initiative (Chen and Naughton, 2016).

The implementation of SEI takes place in parallel to the discussions of the 12th Five-Year Plan and during a period of great turbulence in the international scenario, where the central countries were beginning to reveal industrial and technological policies aimed at accelerating the 4th Industrial Revolution (Lee et al., 2020). On the domestic front, the Chinese economy began to face difficulties in maintaining high levels of growth, based on the investments in capital-intensive and infrastructure-related industrial sectors (Lewin et al., 2016).

If the MLP brought the theme of endogenous innovation to the heart of the discussion, emphasizing the need to reduce dependence on foreign technology, the term that has gained prominence since Xi Jinping came to power was National Innovation-Driven Strategy (Fu, Mackern, and Chen, 2021; Chen et al., 2021).

Concerns about increasing innovative capacity and reducing dependence on foreign technology are explicit in Made in China 2025, launched in 2015. In addition to establishing a set of 10 sectors (new generation IT; high-end computerized machines and robots; space and aviation; maritime equipment and high-tech ships; advanced railway transportation equipment; new energy and energy-saving vehicles; energy equipment; agricultural machines; new materials and biopharma and high-tech medical devices) considered key for future development, the document listed a set of goals, including indicators of innovation, patents, product quality and reduction of pollutant emissions (Wübbeke et al., 2016).

Also launched in 2015, the Internet Plus Plan sought to integrate the internet and digital activities into society and the economy. This goal was divided into four pillars. Using ICT to make manufacturing and service sectors more efficient and competitive globally was the first goal. Second, small and micro enterprises were encouraged to develop apps and platforms. A third goal was to expand credit to small and microbusinesses, which are less well served by traditional credit systems. A fourth objective was to spread communication networks to rural areas. The plan also stressed the need to accelerate the implementation of 5G (Arcesati et al., 2020).

In 2016, the Communist Party Central Committee and the State Council issued the National Innovation-Driven Development Strategy. Cheung et al. (2016) highlight how the National Development and Reform Commission (NDRC) and Financial and Economic Affairs Leading Group (FEALG) led the formulation of this strategy and its translation into concrete actions, which demonstrates the high degree of priority given to it by CCP. The actions would be established in three stages. The first would be to make China an innovative country in 2020, which would mean creating an environment more conducive to innovation, with better conditions for the protection of intellectual property and better incentives and regulations to spread innovative activities. In 2030, the goal is to join advanced countries in terms of innovation in selected areas. And finally, in the third stage, which would coincide with the centenary of the revolution, to become a leading country in terms of innovative capacity.

AI was already receiving increasing attention within the more general strategy of innovative development in China. One year after the launch of the Internet Plus, for example, a document was added with goals and actions aimed specifically at Artificial Intelligence, the 'Internet Plus and AI Tree-Year Implementation Plan'. Also in 2016, AI appeared as one of the key areas within the Five Year Plan for the Development of Emerging Strategic Industries, but it was only in 2017 that the 'National New Generation Artificial Intelligence Development Plan' (AIDP) was officially launched.

2 – THE NATIONAL NEW GENERATION ARTIFICIAL INTELLIGENCE PLAN

The launch of AIDP, in addition to the different initiatives highlighted in the previous section, reinforced, on the one hand, the importance of mastering the technological frontier sectors. On the other hand, it was also the result of increased international competition for technological leadership within the Industry 4.0 (Castro et al., 2019; CISTP, 2018).

AIDP announced China's plans to foster research and support technology adoption in a wide range of sectors, such as social welfare, environmental protection, and national security. The outline of the plan highlights the need to drive innovation and leverage transformations towards a 'smart' economy and society based on AI. The government stood out as a major driver of the process, but great emphasis was placed on the need to strengthen links among private companies, research institutions and military bodies to promote mutual development (Roberts et al., 2021).

The AIDP strategic assessment explicitly recognizes the gap between China and developed countries concerning basic research, development of algorithms and key equipment, semiconductors, software, skilled labor and a structured ecosystem. Hence the need for coordinated actions aimed at fostering the private sector, providing basic infrastructure and advancing regulatory and standardization rules (Ding et al., 2018; Webster et al., 2017).

In its goals, AIDP sets the target of achieving, by 2025, significant advances in basic research, technologies, and AI applications, listing them as drivers for upgrading and productive transformation. In 2030, the aim is to reach levels compatible with the competition for global leadership in terms of innovation, obtaining relevant results in the construction of an 'intelligent' economy and society, capable of paving the way to becoming an economic power.

For the construction of this future scenario, the Plan highlights the need to advance in both theoretical and basic research and the development and diffusion of technological systems. A number of AI fields have been highlighted to promote disruptive changes in the future, including big data intelligence, cross-media intelligence, swarm intelligence, autonomous intelligence systems, high-level machine learning theory, brain-inspired intelligence computing theory, and quantum computing theory (Webster et al., 2017). The development of open and stable systems, the integration of algorithms, data, and hardware, as well as leveraging sensors, recognition systems, cognitive reasoning, movement execution, and human-machine interface, are also concerns. Consequently, these systems should be encouraged to shape productive activities, enabling relevant productivity increases and the dominance of upper-end value chains by promoting the convergence of artificial intelligence in all important economic sectors.

In addition, AIDP emphasizes AI's application to addressing relevant social challenges, such as improving education, health, social assistance, urban mobility, smart cities, and public security. Social control and surveillance are also very important and controversial issues that have been made possible by the diffusion of these technologies in China but are beyond the scope of this paper (Creemers, 2017; Roberts et al., 2021).

It is also important to emphasize that AI is an important technology for civil-military integration. According to the Plan, civilian research institutes and universities should be integrated with military research institutes, with a two-way road promoted for knowledge and technology generation, so that their developments will be able to support the development of military command and decision strategies as well as defense systems and equipment. Kania (2021) points out that the

Chinese military strategy of becoming a world-class force has driven the search for advanced equipment, significant investments in robotics, and applications of artificial intelligence and machine learning to intelligent weapon systems, such as unmanned vehicles and missile systems. In the same vein, Allen (2019) points to the assessment of the Chinese military sector that the advancement in the field of AI may result in a leap in its deterrence capacity, including regarding its main western rival. Meanwhile, the developments in artificial intelligence can be applied to civilian applications as well.

Despite the strong influence of government planning, through the AI Strategy Advisory Committee, the Ministry of Science and Technology (MIST) and the Ministry of Industry and Information Technology (MIIT), and the various support instruments for research institutes and universities, the role reserved for the business sector must also be emphasised.

The fact that data plays a crucial role in value creation has increased the role of private companies in the innovation system, as the control of data on digital platforms is becoming increasingly important. According to Yu et al. (2021) in the industry-university relationship, the AI companies are supplementing some functions of the universities in generating basic knowledge and cultivating talent, while the university needs more collaboration with industry to advance scientific research. Likewise, government-industry relations are shifting from a commanding to a more collaborative mode, as digital platforms control valuable data and pioneer expertise, and they become more influential in defining regulations.

Business actors include technological giants such as Baidu, Alibaba and Tencent. However, there are companies more specialized in artificial intelligence such as iFLYTEK, Face ++, SenseTime and iCarbonX. Among these companies, there is even a division of specialization areas, with companies concentrating efforts and opening laboratories focused on innovation in specific application fields such as Baidu in autonomous driving, Alibaba in smart cities, Tencent in medical imaging and Sense Time in computer vision (Development Solutions Europe Ltd., 2018).

As a result of this initiative, Alibaba has advanced in the packaging of solutions dedicated to Smart Cities and has already implemented its City Brain project in more than two dozen Asian metropolises. It is worth noting that this initiative, commonly financed by the Chinese Development Banks, materializes in the internationalization of technological standards created by local companies, using the strategy (Naughton, 2021) calls the Digital Silk Road. Following Alibaba's lead, several other Chinese AI companies are going on the same internationalization path. Among them are iFlytek (voice recognition), SenseTime (with operations in several areas such as autonomous vehicles, medical services, etc.), Megvii (image recognition and deep learning), among others.

Taobao Villages, also coordinated by the Alibaba Group, uses the same AI knowledge base to integrate rural villages into its marketing platform. By integrating local production with a wide range of diversified suppliers into the platform, and by using artificial intelligence tools to identify patterns of consumption and demand fluctuations, the idea is to make a revolution in the production based on artificial intelligence possible (Schneidemesser and Butollo, 2022).

WeChat, Tencent's internationally recognized platform, also plays a critical role in advancing digitalization and the ubiquitous application of services increasingly enabled by AI. Such a platform, with over 900 million users, is ubiquitous in the daily life of Chinese urban residents and is the origin of a multitude of apps that utilize artificial intelligence to give users new services, as well as new ways to use virtually all typical services of modern life.

In addition, the structuring of investment funds targeting technology-based companies is considered a means of promoting AI start-ups. These funds involve private resources, as well as 'government guided funds', which are partnerships between central or local governments and other investors, usually state-owned enterprises, financial institutions, as well as private investors (Beck, 2023; Development Solutions Europe Ltd., 2018). Venture capital funds, equity investments, and risk compensation mechanisms are important resources for transferring, capitalizing, and commercializing the technology results of start-ups and SMEs in strategic areas and stages.

3 – CHINESE AI EVOLUTION IN THE GLOBAL SCENARIO

This section aims to provide indicators on China's progress in terms of the development of AI, allowing to assess its relative position in the global scenario, considering different dimensions. Since China's AIDP was launched only recently, it is still not possible to assess all its effects and results, which, in addition, aim for the long term. However, the data collected brings a broad view of some of the observed advances, within the context of international AI dispute.

Although there are no consolidated metrics or indicators that allow us to accurately assess how far China has advanced in its strategy and what results have been achieved in its AI plan, the extensive bibliographic review carried out for this paper (Ashwin Acharya Zachary Arnold, n.d.; Baruffaldi et al., 2020; Castro et al., 2019; CISTP, 2018; Ding et al., 2018; Murdick and Thomas, 2020; WIPO, 2019; Zhang et al., 2021) converged to point that the most frequent dimensions[1] involve the analysis of the following topics: i) indicators of scientific progress measured mainly from publications in journals; ii) technological results, analyzed mainly from patent information; and iii) business involvement and corporate investments.

One of the main indicators explored in several studies on AI-related technologies is the evolution of AI-related publications. Among the various sources, two stand out, due to the wide data accessibility.

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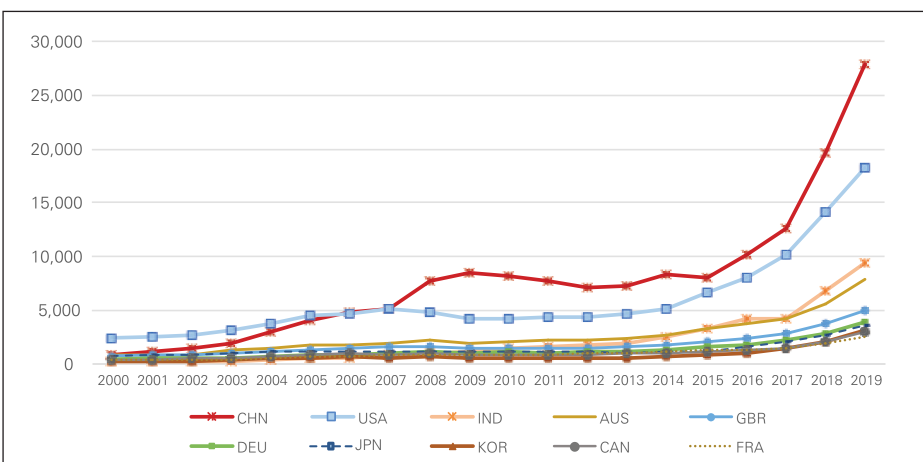
[1] Some publications, such as Zhang et al. (2021), also analyzes undergraduate and graduate training in AI, as well as supply and demand for workers, based on information from Linkedin. The lack of international comparability of this information, however, justifies its omission from the analysis.

The first one is the Scopus database from Elsevier, which has more than 81 million peer-reviewed documents. From this database, Elsevier uses a set of keywords to perform searches and organize information about papers related to AI. The second one is the Microsoft Academic Graph (MAG), which performs automatic searches on a wide range of documents such as books, papers in journals and conferences and articles in magazines. For this paper, only publication in journals was considered.

Considering firstly the information from Elsevier/Scopus, it is possible to note the first wave of increase in publications between 2000 and 2009, followed by a period of relative stability that remained until 2014 (Figure 1). From 2015 onwards there is a new wave of increase with the total of publications worldwide in AI reaching just over 120 thousand papers in 2019, which represented 3.8% of all journal publications from the Elsevier/Scopus database.

The fast growth of Chinese publications since the series began allowed the country to overtake the United States in 2008. However, Chinese publications remained relatively stagnant until 2015, when it again started a trajectory of intense growth. In 2019, total Chinese production was around 28,000 papers, representing 23% of world scientific journal AI publications. The United States, as well as all European Union countries, had around 18,000 papers (about 15% of the total). It can be observed, therefore, that in the most recent period, China's Science and Technology system has responded to government incentives to insert AI at the center of its strategic areas.

Figure 1: AI publications in peer-reviewed journals.
Top 10 Countries. 2000-2019



Source: Zhang et al. (2021), data from Elsevier/Scopus. Available at https://drive.google.com/drive/folders/1CgMBVb4p6BikFBTziFqdDY4lPkcP1Cij. CHN = China, USA = United States, IND = India, AUS = Australia, GBR = Great Britain, DEU = Germany, JPN = Japan, KOR = Korea Rep., CAN = Canada, FRA = France.

Apart from covering a wider range of journals than Elsevier/Scopus, the MAG database allows checking the quality of the journals. The total number of publications between 2016 and 2020 in journals in the top 10% highest ranked are shown in Table 1.

The United States does not only outperform China in terms of total journal publications, but also in terms of top 10% journals, according to MAG. In the United States, 16% of papers are published in top 10% journals, while in China, 10% are. Although Chinese publications are still significantly behind those published in the United States, they rank well above other countries that appear next in Table 1, such as the UK and Germany. It is not very different from Germany or Australia in terms of the proportion of the top 10% in the total.

Table 1: AI publications in all journals and top 10% journals.
Top 10 Countries. 2016-2020

Country	A - Top 10%	B - Total	A/B (%)
United States	52,016	317,552	16%
China	25,685	269,804	10%
United Kingdom	10,724	79,629	13%
Germany	6,332	56,879	11%
Canada	4,890	45,590	11%
Australia	4,434	41,976	11%
Italy	3,670	39,876	9%
India	3,466	67,709	5%
France	3,264	35,181	9%
Netherlands	2,723	24,042	11%

Source: OECD (2021). OECD.AI, powered by JSI using data from MAG. Available at www.oecd.ai.

It is worth mentioning that in the analysis carried out by Baruffaldi et al. (2020), from the 10% of most cited papers (and not according to the journal ranking as in Table 1) between 2016 and 2018, China recorded a share of 22.1%, followed by the European Union, with 21.9% and the United States, with 20%.

A database recently organized by the Center for Security and Emerging Technology (CSET) confirms that the increase in Chinese share occurs not only quantitatively but also qualitatively (Acharya and Dunn, 2022). The CESET database has compiled information from several sources[2], including Clarivate's Web of Science (WOS), Digital Science's Dimensions (DS), Microsoft Academic Graph (MAG), China National Knowledge Infrastructure (CNKI), preprints from ArXiv and machine learning papers from Papers With Code. Within the set of publications,

[2] These publications were organized into research clusters, defined as a group of publications that cite one another more than they cite publications outside of the cluster. CESET analyzed the database of publications that appear in research clusters with significant AI-relevant content.

emphasis is given to those with high impact, corresponding to the 95th percentile or above, which totalled 170 thousand publications.

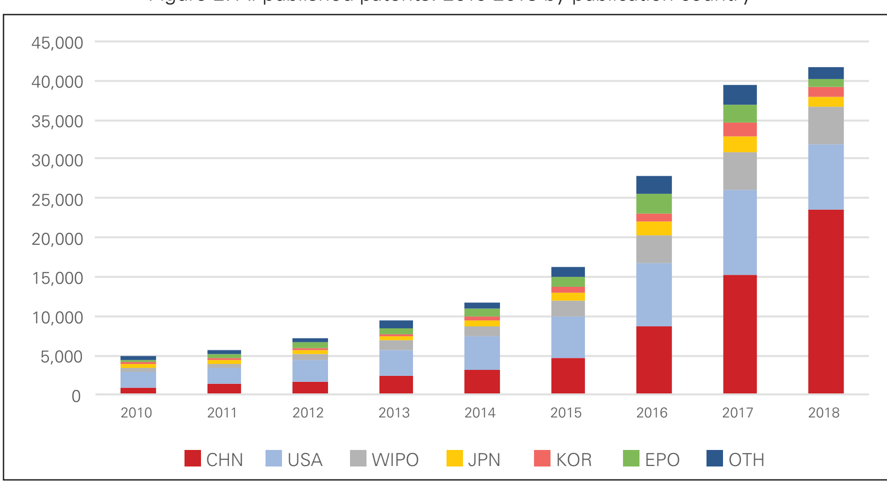
The results show a significant increase in the participation of Chinese authors in high-impact AI publications. In 2005, China had a share of just over 10% of the total. The growth has been continuous since then, accelerating from 2015 to reach 38% in 2019. In the United States, the share fell from 45% in 2005 to 39% in 2019.

Science publications indicate the effort involved in generating and disseminating knowledge, but how that knowledge is turned into technological progress depends on several other factors, including business efforts to launch innovative products and services, and government policies that foster innovation across the nation. As discussed in the previous section, the Chinese AIDP sought to articulate an innovative ecosystem, promoting not only Universities and Research Institutes, but also the private sector. The results of these efforts are traditionally measured by patent analysis.

In general, despite the different databases and methodologies for classifying AI-related patents[3], several studies indicate that growth has been rapid, especially since 2012 (Baruffaldi et al., 2020; CISTP, 2018; Murdick and Thomas, 2020; WIPO, 2019; Zhang et al., 2021).

According to the data collected by CSET and 1790 Analytics (Murdick and Thomas, 2020), China is playing an increasingly important role within this growth trend (Figure 2). In 2016, AI patent filings in China surpassed the United States and became the world's leading country.

Figure 2: AI published patents. 2010-2018 by publication country



Source: Murdick and Thomas (2020), CSET and 1790 Analytics.
Available at https://github.com/georgetown-cset/1790-ai-patent-data.

[3] See Baruffaldi et al. (2020) for an in-depth discussion of different methodologies for capturing patents involving AI.

One of the key aspects to consider when assessing the evolution of China's performance through patent analysis is the impressive growth in applications at the Chinese patent office in the recent period. Several authors (Jefferson and Jiang, 2021; Murdick and Thomas, 2020) have highlighted the role of incentives, subsidies and the establishment of patenting in officials-rank standards in that advance. A number of patents would tend to increase in quantity, but not necessarily in quality, making it difficult to establish a direct relationship between patents and increase in inventiveness of Chinese agents. On the other hand, Murdick and Thomas (2020) point out that the recent surge of AI patents in China has coincided with a rise in international patent applications through the PCT, indicating that quality has also increased.

According to WIPO (2019), despite China being the patent office which is most frequently chosen as the office of first filing, ahead of the United States, considering the highly cited patents and the proportion of patents with applications for international extension, China's position ended up after the United States, Japan, South Korea and Germany. In the analysis carried out by the China Institute for Science and Technology Policy (2018) and WIPO (2019), it becomes evident that, while in the case of the United States, Japan and advanced countries in Europe, companies are generally the main depositors of patents, universities and research institutions play a more significant role in China. One possible reason is that they are more influenced by official-rank standard evaluation than enterprises.

In the analysis of Baruffaldi et al. (2020), only the AI patent families classified as belonging to IP5 were considered, that is, registered in at least 2 of the 5 main worldwide patent offices (United States, Europe, Japan, South Korea and China). This methodology reduces national bias in patent statistics and, at the same time, works with a subset of patents with greater quality and commercial potential, given depositors' desire for legal protection in at least 2 of the largest offices worldwide. Considering the requests that occurred between 2014 and 2016, the information showed that inventors based in Japan accounted for 29% of the total, followed by the United States with 25% and China with 13%. It is worth mentioning, however, the speed of Chinese growth, since in 2004-2006 the Chinese share was only 2%. At the same time, the data fail to capture the more recent growth of Chinese fillings, as pointed out in Figure 2.

Only private companies are considered in Table 2, according to data from CESET PARAT[4] (Private-sector AI-Related Activity Tracker). The United States has a clear lead, with nine companies among the top 20 patent applicants between 2010 and 2020, with IBM, Microsoft, and Google occupying the top three spots. China, on the other hand, appears in second place, with five companies (PingAn, Baidu, Tencent, Alibaba, and Huawei). Chinese enterprises come out ahead of companies from Japan (3 companies), South Korea, Germany and the Netherlands (1 each).

It is thus observed that in China, as in the United States, the Tech-Giants are

[4] https://parat.cset.tech/.

playing a leading role in exploring opportunities in AI-related technologies development and application. The gains arising from network externalities and the possibility of co-specialization with other relevant areas in the digital economy, such as cloud computing and big data, give these companies the opportunity to exploit dynamic economies of scale and a strong advantage over competitors.

Table 2: AI patents and publications by private companies. 2010-2020

Rank	company	country	AI Patents Since 2010	AI Publications since 2010	AI publications in Top Conferences since 2010
1	IBM	United States	3,539	7,722	1,555
2	Microsoft	United States	1,741	10,371	3,690
3	Google	United States	1,565	7,776	2,865
4	Ping An	China	1,391	142	15
5	Baidu	China	1,328	1,219	511
6	Samsung	South Korea	1,275	2,380	278
7	GE	United States	1,148	1,007	69
8	Tencent	China	1,041	2,137	904
9	Intel	United States	977	1,673	246
10	Siemens	Germany	867	2,278	159
11	Nec Corp.	Japan	748	716	119
12	Alibaba	China	650	1,830	808
13	Toyota	Japan	545	763	38
14	Huawei	China	527	1,726	452
15	Facebook	United States	513	2,522	1,091
16	Qualcomm	United States	501	468	58
17	Amazon	United States	442	1,851	630
18	Philips	Netherlands	394	1,214	36
19	Adobe	United States	389	1,600	575
20	Sony	Japan	369	271	19

Source: CSET (2022). Private-sector AI-Related Activity Tracker. Available at https://parat.cset.tech/.

Table 3: Corporate Investment In AI, 2016-2020. US$ million

Country/ Region	2016	2017	2018	2019	2020	2016-2020	%
			US$ million				
China	2,831	6,493	15,252	10,973	13,426	48,974	22.4
United States	9,124	15,967	18,464	27,171	39,124	109,850	50.1
Europe	1,047	17,636	3,418	4,445	7,145	33,692	15.4
Total	17,578	43,992	43,396	48,814	65,308	219,089	100.0
			Number of transactions				
China	100	158	261	369	283	1,171	11.0
United States	712	969	1,201	1,243	1,093	5,218	49.1
Europe	216	370	489	536	491	2,102	19.8
Total	1,243	1,842	2,463	2,717	2,367	10,632	100.0

Source: Zhang et al. (2021). data from CapIQ, Crunchbase, and NetBase Quid, 2020. Available at: https://drive.google.com/drive/folders/11dIp56lhuka6bbe52nbkVCywj0orZG54.

While large companies dominate the AI industry, there is also an intensive movement among start-ups and small technology-based companies, as evidenced by corporate investments. Table 3 shows information about private equity and venture capital investments in start-ups in an industry that is still undergoing consolidation. It's possible to see the strong increase in investments, from US$ 17.5 billion in 2016 to US$ 65.3 billion in 2020. Considering the number of transactions, the total was 1,243 in 2016 and reached 2,367 in 2020. The table shows how the competition for establishing an ecosystem of companies developing and applying AI algorithms has been strong, especially in the United States and China, and to a lesser extent, in European countries.

According to the accumulated values, the United States represented about half of the transactions and registered values. China accounted for 22.4% of values and 11% of transactions. The average value per transaction seems to reflect the strategy of capitalization of Chinese companies through the organization of government guided funds described in the section 2 and the most prominent role of Chinese tech giants highlighted in Table 2. In European countries, the opposite is true, that is, participation is greater in the number of transactions (19.8%) than in the value of transactions (15.4%).

FINAL REMARKS

Techno-nationalist strategies have been amplified by the intensification of global competition after the 2007-200808 crisis, which has sped up the process of changing the techno-productive paradigm. National policies to promote Industry 4.0 have intensified and accelerated transformations in several interrelated scientific and technological fields.

This movement represents an unprecedented challenge to Chinese productivity and technological catching-up. Moreover, it must be acknowledged as a catalyst for strengthening indigenous innovative capacity as outlined in the MLP. In the National Innovation-Driven Development Strategy, science, technology and innovative capacity have become the foundations of Chinese economic and social development.

This paper examined how AI promotion has played a key role in STI and industrial policy since then. Because AI technologies are pervasive in other areas of Industry 4.0, they are central to determining the creation and distribution of value among the agents integrating hyper-physical systems. In addition, the national development of AI also has other substantial impacts on China's position in the international geopolitical system, given civil-military integration.

Government resources and policies related to AI in China indicate the government's recognition of these technologies' significance for the country's long-term development. A key objective of the paper was to highlight the rapid and intense Chinese advances in AI technological and scientific production. Based on a variety of databases and methodologies, this progress in both quantitative and qualitative dimensions was noted. Currently, China is the leading nation in AI publications and has rapidly closed the gap with the United States in terms of publication quality and impact.

Similar results have been observed in patents. China is already the country with the highest number of AI patent filings. Quality and quantity are also important here. The information analyzed shows that the United States is still leading the way when it comes to patents with significant commercial potential and protected internationally. However, there is also rapid development in China. The share of Research Institutes and Universities in China in the total patent request is proportionally greater than in countries with more mature national innovation systems such as the USA, Japan and some European countries. Despite this lesser representativeness of the business system, in general, there has been a rapid advance in the technological skills in AI of leading IT companies (such as PingAn, Baidu, Alibaba, Tencent and Huawei). These companies are the Chinese counterparts of US tech giants such as IBM, Microsoft, Google, Intel, Facebook and Amazon.

Corporate investments also point towards the formation of a powerful innovation ecosystem, with significant capitalization movements through private investments, public offerings, mergers and acquisitions, and the purchase of minority interests.

The area of AI has undergone significant changes in recent years. The Chinese AIDP was also released recently. To carry out a definitive assessment of China's position and progress in AI is still very difficult. However, it is undeniable that progress has been fast, and that China is one of the countries contending for global leadership. While the information given throughout the paper emphasizes the still-strong leadership of the United States, China is no doubt its main competitor.

Having the ability to compete for leadership in a frontier sector is without a doubt a remarkable achievement and a considerable advance for a country that, not so long ago, had to follow in the footsteps of developed countries in terms of technological advancement.

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