China's catching-up in Artificial Intelligence seen as a co-evolution of Corporate and National Innovation Systems

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Funding:

There is no particular funding to declare in relation to this paper.

Abstract

Inspired by Christopher Freeman's work on how radical technical change opens up for shifts in world leadership and on the role of innovation systems in this process, this paper explores China's emergence as a lead country in artificial intelligence as reflecting a co-evolution of Corporate and National Innovation Systems. Taking Freeman's (1987) work on Japan as our lead, we focus on the domestic interaction within and on the openness of China's national innovation system. To follow up on his prediction of the increasing importance of big companies as network leaders, we introduce the concept "corporate innovation system" with special attention to two Chinese tech giants: Alibaba and Tencent.

Keywords

Catching-up. Corporate Innovation System. National Innovation System. Christopher Freeman. China. Big tech.

JEL codes: O310; O33; O34; O38

1. Introduction

Our contribution is inspired by Christopher Freeman's work on how radical technical change opens up for shifts in world leadership and on the role of innovation systems in this process (see Box1). To follow up on his intuitions on the increasing importance of big companies becoming network leaders (Freeman and Louçã, 2002, p. 330), we introduce the concept "corporate innovation system". We propose that the catching-up process is an outcome of a co-evolution of national and corporate innovation systems, where the latter is controlled by a dominant firm and constituted by a multitude of more or less subordinate firms and knowledge institutions.

The national innovation system (NIS) concept is rooted in insights showing that innovation is an interactive process (Lundvall, 1985). Enterprises do not innovate alone, and the innovation performance of a national economy reflects the quality of relationships among firms as well as their interaction with the domestic technological infrastructure (Freeman, 1982). Freeman's (1987, 1982) early work on NIS points to the need for catching up economies to manage the openness of the system in such a way that it contributes to building domestic technological capabilities.

In this respect, a recurring theme of this paper is how China (and its tech giants) has combined degrees of openness with building (and drawing upon) domestic technological capabilities. At the corporate level, we outline how Alibaba's and Tencent's innovation activities rely on knowledge sources within China's NIS and on privileged access to Chinese data. Nonetheless, they combine this sourcing with diverse international collaborations, organizing research and development (R&D) way beyond China. We argue that while they contribute to strengthening China's geopolitical positioning, they also challenge the Chinese state's prerogative to manage and steer the economy.

The paper is organized as follows. Section 2 specifies the inspiration from Chris Freeman's work and explains how it relates to the corporate innovation system concept. In section 3, we define AI as a strategic technology. Section 4 highlights some features of China's NIS of critical importance for its catching-up in AI. Section 5 compares Alibaba's and Tencent's corporate innovation systems with those of Google, Amazon and Microsoft concerning AI development, geographical reach and collaborations. Section 6 discusses the results in terms of the co-evolution of national and corporate innovation systems. Section 7 concludes by further elaborating on Freeman's legacy.

Box 1. Key references to Freeman's contribution on technological revolutions, techno-economic paradigm and catching up (1982-2002).

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2. In the spirit and tracks of Christopher Freeman

This article is in honour of Christopher Freeman, and we take inspiration from his work. It is not, however, an attempt to give a general appraisal of his contribution to social sciences or to his outstanding role in the formation of younger generations of scholars. Fagerberg et al. (2011) gave an excellent overview of his contributions in both respects. Instead, we have aimed at an article written in his spirit. We follow him in attempting to understand, what we see as the most pertinent new emerging issues in world development, using and further developing ideas and concepts that preoccupied him, especially after he retired from the directorship of SPRU.

At least since 1980 and until he passed away, Freeman pursued a research agenda with a double aim: to develop an alternative to neoclassical economic growth theory and to explain the evolution of the world order. Why do some countries catch up while others fall behind? What is the basis of world hegemony and how to explain that a latecomer country can forge ahead and become world leader?

To simplify, Freeman's theoretical framing is constituted by two basic elements, the uneven (but not completely irregular) development of technology and the NIS.[1] He uses the theory of shifting techno-economic paradigms, as developed by Carlota Perez, to establish the necessary link between the two concepts (Freeman and Pérez, 1988). In Freeman and Louçã (2002) and elsewhere, he combined historical analysis with attempts to quantify economic processes as characterized by long waves of growth and stagnation.

Freeman (2002) linked technological revolutions to shifts in global leadership. He explained that, in the 18th century, Britain's NIS had developed characteristics (and systemic coherence) contributing to explaining why it became the homestead for the industrial revolution based upon steam power and textiles. As new technological systems dominated by electricity and chemistry emerged, Germany and the United States (US) forged ahead and left Great Britain behind. Freeman's (1987) analysis of Japan's emergence as a potential technological leader in an era of information technology illustrated this general hypothesis.

[1] To the best of our knowledge, the first use of the term 'national innovation system' can be found 1982 in Freeman's working paper and contribution to the OECD working group on Science, Technology and Competitiveness published more than 20 years later (Freeman, 1982). Here, he linked the concept national innovation system to Friedrich List's idea of national wealth as rooted in 'intellectual capital' (Geistliches Kapital). The working paper demonstrated that while List was critical to the free trade doctrine, he was aware that national economic development depends on access to global knowledge: "The present state of nations is the result of the accumulation of all discoveries, inventions, improvements, perfections and extertions of all generations which have lived before us; they form the mental capital of the present human race, and every separate nation is productive only in the proportion in which it has known how to appropriate these attainments of former generations, and to increase them by its own acquirements." (List, 1841, p. 183). Both List and Freeman regarded state participation in international economic relations as a prerequisite for economic development in less developed countries. But they did not regard self-sufficient innovation systems, i.e. extreme forms of techno-nationalism or indigenous innovation as realistic strategies.

In what follows, we go beyond Freeman's analysis in two respects. While most of his work was on innovation in relation to manufacturing, which was true also for his analysis of Japan (Freeman, 1987), we focus on AI and its application in the production of digital services. Second, we propose the concept "corporate innovation system", as an international network organized by a lead firm. Freeman's late work points us in these directions.

2.1 Corporate innovation systems

Freeman and Louçã (2003) consider the formation of corporate networks and the question of power within those networks.

> The fact that networks are everywhere forming, flourishing, and sometimes disappearing does not dispose of the question of power within networks. A network may seldom be a partnership of equals. Some partners are usually more equal than others, to use Orwell's satirical comment on Stalinist forms of equality. A network may be the organizational means whereby a dominant firm maintains control over its suppliers, whether of materials, components, or technology (Freeman and Louçã, 2002, p. 330).

Our Corporate Innovation System (CIS) concept picks up and further develops this insight. The concept was originally defined by Granstrand (2000, p. 13) as:

> the set of actors, activities, resources and institutions and the causal interrelations that are in some sense important for the innovative performance of a corporation or groups of collaborating companies and other actors (e.g. universities, institutes, agencies).

In this paper, we focus on CIS organized around and dominated by a single firm. We emphasize that, by organizing a CIS, tech giants provide the general orientations and desired results to other participants, of course without being able to anticipate every step and leaving degrees of autonomy to subordinate actors. The evolution and performance of the CIS reflect both the lead firm's internal efforts and how it creates access to external knowledge. The former includes investments in R&D, training of employees and building learning organisations. They also encompass the formation of new capabilities attained through hiring.

The acknowledgment of a central planning and organizing capacity of leader corporations is not new. The Global Value Chain (GVC) literature has studied unequal relations within value chains organized by leader corporations (Gereffi, 2014; Gereffi et al., 2005, 1994; Ponte and Sturgeon, 2014; Sturgeon, 2009). The industrial architecture concept also considers how value is created and distributed within productive structures (Jacobides et al., 2006). However, these approaches do not focus on the innovation process (Chaminade et al., 2016; Jurowetzki et al., 2018) and, in contrast to GVC, the CIS encompasses horizontal as well as vertical transactional relationships.

On the other hand, most of the literature that concentrates on innovation overlooks power asymmetries (Chaminade et al., 2018; Jurowetzki et al., 2018; Lundvall, 2002) and knowledge predation. This is also the case of the literature on platforms and ecosystems (Adner and Kapoor, 2016; Cennamo and Santalo, 2013; Gawer and Cusumano, 2014; Jacobides et al., 2018; Stallkamp and Schotter, 2019). Indeed, according to Jacobides et al. (2018), ecosystems are seen as constituted by interacting organizations *not hierarchically managed*.

In what follows, we take inspiration from Freeman's hypothesis that, from time to time, the emergence of radically new technologies upsets the world order. We regard China's ongoing catching-up process as reflecting its growing strength in AI. To that end, we briefly refer next to why AI is crucial for China.

3. Artificial intelligence at the core of the second phase of the ICT revolution

On the input side, AI (making machines think like humans and mimic their actions) draws upon existing ICT technologies such as the internet, mobile communication and supercomputers, and upon a diversity of scientific fields, ranging from computer science, statistical and mathematic models to biology, linguistics, psychology and neuroscience (Nilsson, 2010). On the application side, it has been conceived as an enabling technology (Heaton et al., 2020) and as a general-purpose technology (Brynjolfsson et al., 2017; Dosi and Virgillito, 2019).

Since the 1950s, enthusiasts have presented AI as a promising field. However, until recently, it has proven difficult to move from general ideas to broad applications (Mansell and Steinmueller, 2020, p. 56).

Related scientific publications and patents evidence the acceleration of knowledge production in this technology. From 1960 until early 2018, there were almost 340,000 patent families and over 1.6 million scientific publications. Patents grew about 8% a year between 2006 and 2011 and 28% a year between 2012 and 2017 (World Intellectual Property Organization, 2019).

Among WIPO's (2019) identified AI techniques, machine learning stands out. It was mentioned in 89% of all the AI patent filings until March 31, 2018. Within machine learning, deep learning is the fastest-growing field in patent filings, with a 175% increase between 2013 and 2016. According to our Web of Science search, there were 38,224 publications including the term "machine learning" in that database in 2019, a 635% increase compared with 2009.

The guidance toward this sub-discipline reflects expectations and incentives. Cockburn et al. (2018, p. 2) conceived machine learning, particularly deep learning, as the "invention of a method of invention". In terms of Jensen et al. (2007), it could be argued that the DUI- and STI-modes of learning are becoming overlayered with a -new- digital learning mode. These technologies, where the central element is that algorithms learn and correct themselves by being fed with big data, have almost unlimited applications. This is the model behind social networks, social media, online gaming, streaming, e-commerce and e-payment.

While AI centrality is not a matter of discussion, there is still a debate in terms of its revolutionary scope. The World Economic Forum (Schwab, 2016) argues that AI is at the core of a new industrial revolution while others, such as Nuvolari (2019) and Brynjolfsson and

McAfee (2014), see the new developments as taking place within the ICT industrial revolution. Jongho Lee and Keun Lee (2021) attempt to solve this debate using USPTO patent data. Based on an analysis of the generality, radicality and length of technology cycles, they conclude that there is no clear indication of a radical break in technology.[2]

Here, we refer to the ICT revolution as constituted by two phases with AI at the core of the second phase and we assume that AI may have the same transformative potential now that microelectronics had in the first phase of the ICT revolution. We raise the possibility that it offers a window of opportunity for China similar to the one that Japan exploited in the 1970s and 1980s. We assume that China's success in catching up depends on how successful it is to build a strong AI technology system –spanning from basic research to end-users– and we see it as shaped through the co-evolution between China's NIS and the CIS of a handful of Chinese tech giants.

High rates of growth in production and trade in digital services (Fu and Ghauri, 2020; WTO, 2019) reflect the explosive growth of tech giants using AI to transform big data into value and innovation. US-based firms -such as Google, Amazon, and Microsoft- got a head start and this gave them a first-mover advantage in wider fields of AI application (Mansell and Steinmueller, 2020, p. 59). The only serious AI contenders reaching the same giant scale -Baidu, Alibaba and Tencent- are rooted in China. All the tech giants are now active in extending the use of AI to important economic and societal sectors such as finance, manufacturing, intelligent cities, education, health, transport and agriculture.

Furthermore, applications in warfare make AI a major factor in determining the military strength of nations. Both the US and Chinese governments have declared AI a strategic technology and given top priority to develop strong AI capabilities. In the US, the National

[2] A caveat on the use of patent data should be stated since AI technologies are often kept secret. For instance, only around 15% of AI published papers disclose their code (Benaich and Hogarth, 2020).

Security Commission on Artificial Intelligence (NSCAI) is co-chaired by Eric Schmidt, the former chief executive of Alphabet (Google's parent company), and Robert Work, the former deputy secretary of defence (Klein, 2020)[3]. Other members are Microsoft's Chief Scientific Officer and Andrew Jassy -former CEO of Amazon Web Services (AWS) and the newly appointed Amazon CEO. Overall, the report makes a strong case for techno-nationalism and, explicitly referring to tech giants' capabilities in the tech war with China, it claims that "even large tech firms cannot be expected to compete with the resources of China or make the big investments the U.S. will need to stay ahead. We will need a hybrid approach meshing government and private-sector efforts to win the technology competition." (National Security Commission on Artificial Intelligence, 2021, p. 25).

The NSCAI-initiative may be seen as a response to China's declared AI ambitions. In July 2017, China's State Council issued the New Generation Artificial Intelligence Development Plan (AIDP), which aims to transform China into the world's AI innovation centre by 2030 (Allen, 2019; Webster et al., 2017). The plan declares that AI in China should be the main driver of industrial upgrading and development.

The role of technological leadership in geopolitical disputes raises interesting parallels to Christopher Freeman's study of how Japan exploited the first wave of the ICT revolution to modernize its industrial system and catch up with the West (Freeman, 1987). To explain the Japanese success, he emphasized the active role of the state, the labour market, the education system and unique characteristics of Japan's industrial organisation (the Keiretsu). This analysis was anticipated in Freeman (1982), which pioneered the use of the NIS concept and presented it as aligned with Friedrich List's infant industry argument (see footnote 2). The Keiretsu organisation of industry, where Japanese business organisations are interlinked

[3] https://www.federalregister.gov/documents/2020/07/07/2020-14587/national-security-commission-on-artificial-intelligence-notice-of-federal-advisory-committee-meeting

through both common ownership and informal network relations, in combination with trade and technology policies, set strict limits to inward foreign direct investment (FDI). Learning from abroad was crucial but it took place mainly through trade, systematic reverse engineering and outward FDI. China's catching up period started differently, with big State-Owned Enterprises (SOEs) entering into joint ventures with foreign multinationals.

In the next section, we present a few key features of China's NIS of relevance for China's catching up in AI. We do so well aware that China's success in realising AI-ambitions will not be determined solely by the strength of its NIS. The geopolitical situation is quite different from when Japan challenged the US technology lead 40 years ago.[4] The US administration as well as the US tech giants regard China as a much more serious threat because of the scale of its economy and the divergent political system. With AI regarded as strategic in military and economic terms, the US may be ready to go far in attempts to curb China's ambitions.

4. China's national innovation system and its catching-up in AI

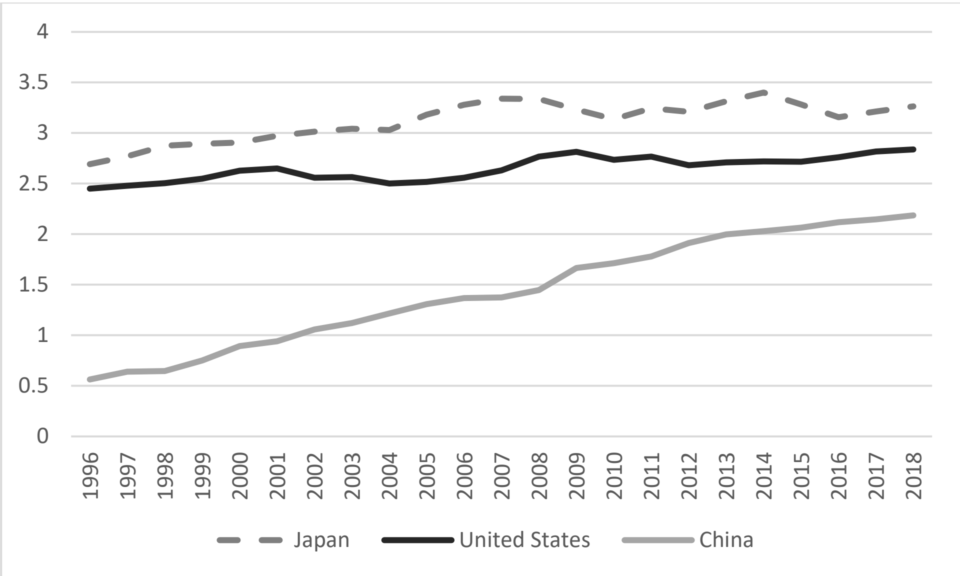
China's innovation system is large, heterogeneous and utterly complex. Regions differ in terms of innovation modes and capabilities. While the central state and the top leaders of the communist party set the general direction for innovation policy, the provinces and lower-level local authorities have a certain autonomy in executing policy, including STI-policy (Gu and Lundvall, 2006a, 2006b). Moreover, huge SOEs -some of them owned by provinces- co-exist with private firms and, as illustrated by Baidu, Alibaba and Tencent and Huawei, entrepreneurship has resulted in the creation of giant corporations operating globally (Liu et al., 2021).

[4] Even then the Japanese success was countered forcefully by the US state in collaboration with multinational enterprises trying to force Japan to make it easier for US companies to enter the Japanese market.

One way to reduce complexity is by presenting aggregated quantitative variables on innovation inputs and outputs. In both dimensions, the trends indicate a rapidly expanding innovation system in China.

In terms of inputs, in two decades, graduates from Chinese universities grew tenfold, reaching 7 million students in 2017, more than doubling US figures (World Bank and DRC State Council, The People's Republic of China, 2019). R&D expenditure also exhibits impressive results (Figure 1). R&D has grown around 20% per annum and R&D as a share of GDP has surpassed the level of the European Union (2.2% versus 2.1% in 2019).[5]

Figure 1. R&D expenditures as a share of GDP. Selected countries



Source: World Bank

As shown in Table 1 and Figure 2, China's output growth in terms of scientific papers and total granted patents has accelerated. China has become the world leader in both.

Table 1. Publication output.[6] Selected countries

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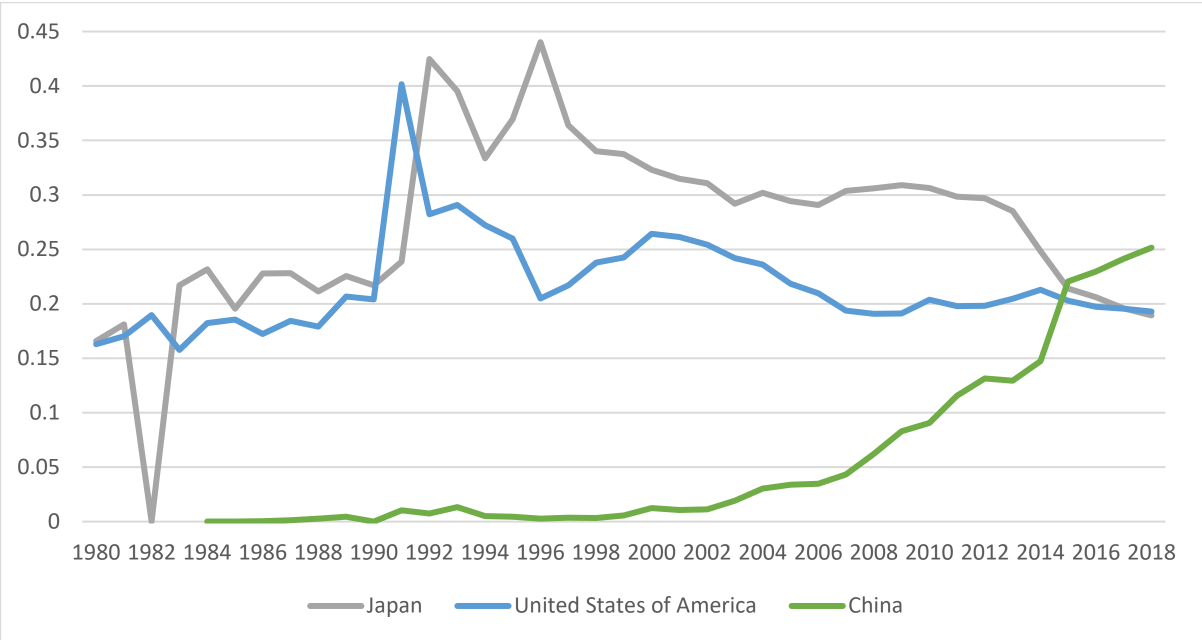
[5] See https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

[6] Data on publication output includes publications from peer-reviewed journals and conference proceedings in science and engineering and indexed in Scopus. One count was assigned to each country or institutional sector involved in co-authoring the article, irrespective of their proportionate involvement in authorship.

	2008	2018	Average annual growth rate 2008–18 (%)	2018 world total (%)
China	249,049	528,263	7.81	20.67
United States	393,979	422,808	0.71	16.54
Japan	108,241	98,793	-0.91	3.87

Source: US National Science Foundation (https://ncses.nsf.gov/pubs/nsb20206/publication-output-by-region-country-or-economy).

Figure 2. Share of total granted patents. Selected countries.



Source: Authors' analysis based on WIPO

There are reasons to assume that these metrics overstate China's position, given current incentive structures and their impact on quality. To access public funding from technology programs, enterprises must document certain R&D and patenting activities (Tseng, 2009; Zhou and Stembridge, 2008). All provinces in China give subsidies to patenting (Li, 2012). At universities, both research grants and salaries depend on the number of publications and patent applications (Quan et al., 2017). Weak quality controls through collegial evaluation systems contribute to inflating figures and low quality output (Fu et al., 2016; Liu et al., 2017). Even so, the numbers indicate a historically unique radical transformation and expansion of China's innovation system.

Aggregate quantitative data give little insight in the workings of the innovation system. In the next section, we briefly discuss one dimension of China's innovation system that we see as especially important for its AI catching up: the management of the openness of the system and how it is related to domestic capacity building. Other equally relevant dimensions are linkages between users and producers of knowledge and corporate governance.[7] Our assessment of China's AI catching-up and our study of the co-evolution between Alibaba's and Tencent's respective corporate innovation systems and China's national innovation system, which constitutes the rest of our paper, will refer to the three dimensions in relation to AI.

4.1 China's ***management*** of the openness of the system

Deng Xiaoping's Open Door Policy of 1979 aimed, among others, to bring modern technology into China. With limited access to foreign currency and limited export capacity, there was little financial room for direct technology import. Much of the increase took the form of joint ventures between multinational enterprises (MNEs) and SOEs that granted the former access to the huge Chinese markets (Feng, 2019).

In an OECD working paper, Schaaper (2009) praises the role of MNEs in technological upgrading in China stating that "the catch-up in high-technology outputs and exports is largely

[7] There is no room here for an analysis of China's innovation system that comes close to matching what Freeman (1987) did on Japan. Such an endeavour would encompass a historical analysis of the role of state in continuously redesigning the innovation system in terms of interaction between knowledge producers and knowledge users (Gu and Lundvall's (2006a, 2006b) and in terms of corporate governance (Liu et al., 2021; Tylecote et al., 2010).

attributable to inward FDI." At the same time, the data presented in the report point to the limits of the openness strategy. By 2005, most of China's high technology exports came from foreign-owned enterprises importing components and using labour-intensive processes to assemble final products. The report also showed that Chinese accumulation of triadic patent families remained extremely low –433 as compared to around 15.000 in the US, Europe and Japan. The 2006 policy shift toward indigenous innovation may be seen as a reaction to the weaknesses reflected in such indicators (Gu and Lundvall, 2016).

Feng (2019) explains that the revision of the open door policy was directly inspired by research on corporate governance and technology management at the enterprise level. The research demonstrated that, in sectors such as telecommunications and automobiles, a trading market for technology had not led to the formation of indigenous technology capacity. The lack of success reflected the combination of the unwillingness of foreign partners to share technology and the lack of incentives for SOEs management to build in-house technological capabilities. Since there was no competition from indigenous producers, multinationals harvested huge profits from the Chinese market, often through the sales of products based upon outdated technologies.

According to Feng (2019), the change of course in the direction of indigenous innovation was inspired by finding that some domestically owned (some of them private) companies increasingly built their competitiveness on technological strength. Prominent examples of private firms were Huawei in telecom and Geely in automobiles.

The strategic shift from imitation to indigenous innovation was implemented with the 2006 – 2020 Plan for the Development of Science and Technology in the Medium and Long Term, where the term "indigenous innovation" became the keyword. It signalled that the openness should be managed differently and that the primary purpose of FDI should be to contribute to building domestic technology capacity. It implied a more selective FDI-openness in terms of technologies and sectors (Bâlgăr, 2020).[8]

Chinese enterprises had already engaged in a different form of global integration through outward FDI since 1999, encouraged by the Chinese government to 'go global'. In 1986, China accounted for 0.1% of global outward FDI stock. This share rose to 0.48% by 2001 and reached 4.9% in 2016 (Buckley et al., 2018). Originally focused on increasing access to resource-based commodities, outward FDI recently changed toward access to technological learning. According to Fu et al. (2018), reverse learning -where Chinese enterprises learn from customers, collaborators and affiliates in developed economies- was of major importance, in particular, for Huawei and ZTE.

As we will see below, the degree of openness remains a critical issue for the Chinese state and China's tech giants. Access to international sourcing of key technologies and hardware such as semiconductors, world-leading talent in AI and data from abroad are crucial for realizing China's AI ambitions. Equally important have been the specificities of different division of labour between universities and tech giants in the development and application of AI, as we explain in the next section.

4.2. China's catching-up in artificial intelligence

In this subsection, we use World Bank, WIPO and OECD data and reports to compare China's NIS AI capabilities with those of the world forerunner -the US- and other core countries. In addition, we retrieved from the Web of Science all the publications with the term "machine learning" and all the publications with the terms "neural network" or "deep learning" both for

[8] Actually, the OECD estimates that such barriers were lowered (Bâlgăr, 2020).

2019. We used these data to proxy the US and China's respective positions in these technologies.

We also considered Allen's (2019) and Ernst's (2020) fieldworks in China. The former included interviews and participative observation in meetings with high-ranking Chinese officials, while the latter mainly interviewed Chinese enterprises.

We argue that the role of the Chinese state and, in particular, the setting and strengthening of China's NIS have been crucial for China's ongoing AI catching up. We also acknowledge that China's AI research mostly relies on its universities and public research organizations and that corporations, in particular tech giants (see section 5), have profited from these institutions engaging less in AI research as compared to the US tech giants. Overall, our analysis outlines that AI catching-up is an ongoing and uneven process where China is already placed among the leaders yet behind the US.

4.2.1. Strengths of China's AI catching-up

A recent report of the Center for Data Innovation found that China is the world leader in AI adoption and data (Castro and McLaughlin, 2021) and different reports have shown that China arrives first in AI publication counts (Castro and McLaughlin, 2021; China Institute for Science and Technology Policy at Tsinghua University, 2018; Stanford, 2021; Zhang et al., 2021). The Chinese Academy of Sciences is the world's first organization in AI publishing with over 26,000 publications until 2017 included, and the second in terms of highly cited papers[9].

Moreover, from a total of 38,224 publications, we found 11,113 (29%) written by at least one US-based author and 8,502 (22%) by at least one China-based author. Similar concentration rates with the US and China as absolute leaders, but with China at the top, can be observed for

[9] Defined as papers that perform in the top 1% based on the number of citations received within a field for a selected year.

publications including the terms "deep learning" or "neural networks". By 2019, from a total of 66,202 publications including either term, China had co-authored 23,186 (35%) and the US 14,685 (22%).

The Chinese state has played a central role in China's AI successes. It has funded AI research at universities and public research institutes and invested heavily in telecommunication infrastructure since the turn of the millennium (Hong, 2015). Moreover, a stepping stone in China's AI catching-up was further developing China's Great Firewall, originally introduced in 1997. It consists of an ensemble of social media regulations, IP blacklists, keyword filters, data gateways and human censors (Tsui, 2007). The Firewall limits access for foreign companies to internet-based business (including cloud services), which favoured local companies in particular Baidu, Alibaba and Tencent (Azmeh et al., 2020; Mueller, 2011; Wu and Gereffi, 2018). The Chinese state also played its part in limiting eBay's expansion in China, thus favouring Alibaba. Tight banking and financial system regulations contributed to delaying eBay's launch of its -back then acquired- PayPal service in China, favouring the expansion of Alipay and Alibaba as a whole (Shen, 2021).[10]

These policies, together with the size of China's population (1.3 billion) and the fast adoption of mobile phone usage (growing from 300 to 900 million users between 2010 and 2020[11]), internet and 4G resulted in a huge amount of data produced and stored inside China. China's datasphere is growing 3% faster than the global datasphere[12] and by 2018 China's total data volume was 23.4% (7.6 zettabytes) of the world's data volume (International Datacenter Corporation, 2019).

[10] Alibaba's displacement of eBay was also enabled by an additional 82 USD million investment of foreign capital (SoftBank, Fidelity Capital, Venture TDF and GGV Capital), pointing to the complex interplay between the Chinese state, its tech giants and foreign capital (see section 6).
[11] https://www.statista.com/statistics/273973/number-of-mobile-internet-users-in-china/
[12] The global datasphere is all the data created and replicated in one year.

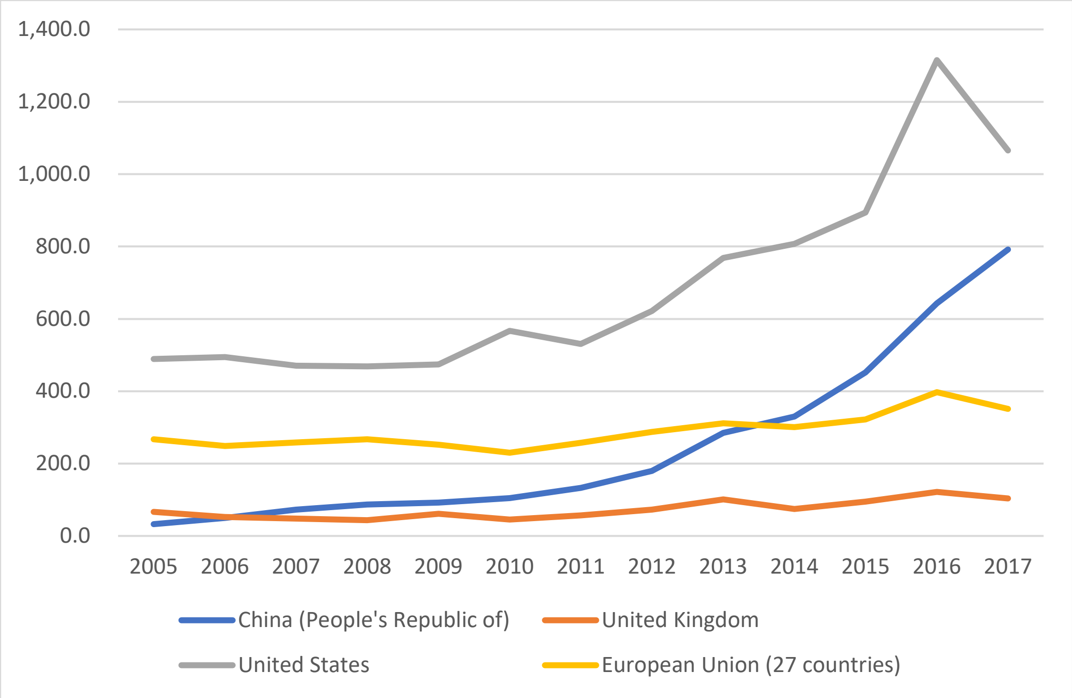
All the latter made it possible for Chinese tech giants to harvest enormous volumes of data –a prerequisite for establishing themselves and China as world leaders in AI applications. China follows the US, with 22% of the value of the world's 70 largest platforms (UNCTAD, 2019). China also comes second after the US in terms of share in the top 100 unicorns by value (PWC, 2020) and in AI companies. By June 2018, there were 4,925 AI enterprises worldwide, 42% from the US and 20% from China (China Institute for Science and Technology Policy at Tsinghua University, 2018).

Two decades after the introduction of the Great Firewall, Alibaba and Tencent are digital forerunners in e-payment and other fintech solutions. They are also among the world leading companies in multiple digital services and platforms. As we show in the next section, Chinese tech giants also rely on the AI-R&D capabilities of Chinese universities and public research organizations, where AI research is mostly concentrated and where the most active AI patent applicants come from.

These results are indicative of a broader technological catching-up of China's NIS in AI, as evidenced by the overall evolution of its AI patent portfolio (see Figure 3).

Figure 3. AI patent counts by inventor(s)'s country(ies) of residence[13]

[13] Inventions protected in at least two jurisdictions, at least one of which needs being one of the Five IP Offices.



Source: OECD data based on IP5 Patent families

4.2.2. Weaknesses of China's AI

In terms of weaknesses, the Chinese leadership is particularly concerned with AI top talent, technical standards, software platforms and semiconductors (Allen, 2019). These weaknesses were emphasized in China's white paper on "Artificial Intelligence Standardization", written between public actors and experts from Baidu, Alibaba, Tencent, Huawei and ByteDance.[14]

To tackle these weaknesses, China's Next Generation AIDP gives priority -among others- to AI international standards' setting. To accelerate the creation of Chinese global AI leaders, the plan advocated for helping AI firms to strengthen their patent structures and take the lead in or participate in the formulation of international standards. It also claims that AI standards' setting should contribute to strengthening military-civilian integration in AI and accelerating AI adoption in countries along China's Belt and Road Initiative, which includes a Digital Silk

[14] https://www.newamerica.org/cybersecurity-initiative/digichina/blog/chinese-interests-take-big-seat-ai-governance-table/

Road. AIDP was followed by the mentioned white paper on "Artificial Intelligence Standardization" as indispensable for accomplishing AIDP goal.[15]

Concerning AI talent, by 2017, Europe more than doubled China in the number of AI researchers (43,064 versus 18,232, respectively) and the US had 56% more AI researchers than China (Castro et al., 2019). Nevertheless, aggregated data from 2015 to 2020 show that China's AI skill penetration[16] rate is 1.40 times the global average. In this indicator, China ranks third after India (2.83) and the US (1.99) (Zhang et al., 2021). It may thus be the case that China's AI-talent demand is growing faster than internal AI-talent supply because of the accelerated but uneven AI catching-up of the country.

Within semiconductors, leading-edge AI chips are critical for processing big data with machine learning (in particular using deep learning). China lags behind leading semiconductor firms whose chips assure computing power at lower costs (Ernst, 2016). Chinese firms occupy a marginal position in the overall chips value chains, including AI chips. Lagging in AI processing power is a fundamental weakness because of its centrality for AI development. In fact, a recent investigation found that 'the compute divide', defined as uneven access to computing power, could be a major reason underlying the concentration of AI research by large technology firms (Ahmed and Wahed, 2020).

Chips are of paramount importance both for the US and China, but it may be argued that the former has an advantage. Although Taiwan's TSMC and South Korea's Samsung are the world leaders in production capacity, with a clear advantage of the former, the US strength comes from the impossibility to produce advanced semiconductors without access to leading US

[15] https://www.newamerica.org/cybersecurity-initiative/digichina/blog/translation-excerpts-chinas-white-paper-artificial-intelligence-standardization/

[16] Shows the average share of AI skills among the top 50 skills in each occupation, using LinkedIn data on skills by member considering positions held and the locations of the positions (Zhang et al., 2021).

players' design technology.[17] This dependence gives the US veto power over chip producers' sales to China -they were for instance forced to cut off supplies to Huawei and ZTE in 2020- and the capacity to pressure them to establish manufacturing facilities in the US.[18]

Ernst's (2020) in-depth fieldwork found that this is forcing China to accelerate AI catching-up in core foundational technologies with many AI-chip initiatives on their way. As part of its AIDP plan, the Chinese government subsidized two of China's lead AI chips firms -SMIC and Tsinghua Unigroup- with over 30% of their respective annual consolidated revenue. However, according to Ernst (2020), SMIC -which seems to be the most advanced- would require at least a decade to close its gap with TSMC.

In terms of other weaknesses, insufficient early-stage R&D has been highlighted in the Chinese government AI megaprojects' guide, referring both to a need to foster fundamental theories of AI and key technologies (Colvin et al., 2020). Differences with the US point to the lower engagement of the private sector. While academia ranks first in AI publishing in both the US and China, corporations are the second most important AI papers' author in the former (19.2% of total publications), whereas in China government occupies the second position (Zhang et al., 2021). Only SGCC belongs to the world's top 20 enterprises in AI paper output occupying the 14th position. This ranking is led by Microsoft and IBM (China Institute for Science and Technology Policy at Tsinghua University, 2018).

Moreover, most of China's top patent owners are non-firm organizations. The only exception is SGCC, which is China's first AI patent holder with 4,246 AI patents between 2013 and 2017. In the same period, the global leader IBM was assigned 7,276 AI patents (China Institute for Science and Technology Policy at Tsinghua University, 2018).

[17] https://asia.nikkei.com/Spotlight/The-Big-Story/US-China-tech-war-Beijing-s-secret-chipmaking-champions
[18] https://www.ft.com/content/b452221a-5a82-4f5d-9687-093b9707e261?segmentId=b0d7e653-3467-12ab-c0f0-77e4424cdb4c and https://en.yna.co.kr/view/AEN20210517005400320

Castro et al. (2019) found that China arrives after the US and the European Union when it comes to AI development considering highly-cited AI patent families, a proxy for commercialization impacts. Nevertheless, this outcome should be questioned because it considers a very long timeframe and private investment in AI R&D in China is a relatively recent phenomenon (Zhu et al., 2018). But even questioning this indicator, China not only lags in the commercialization impact of its patents but, more broadly, in AI economy metrics.

China is ranked 9th considering all the economic metrics of the Stanford University 2020 Global Vibrancy Ranking, which includes skill penetration, an AI hiring index and absolute and relative indicators for AI private investment, and the number of AI-founded companies in the country. As we mentioned above, the US has the greatest number of AI start-ups and China follows. The US also has the highest levels of private equity and venture capital received by AI start-ups (Castro et al., 2019; Zhang et al., 2021). US-based AI start-ups received over 23.6 USD billion in funding in 2020; China ranked second worldwide with 9.9 USD billion (Zhang et al., 2021).

All in all, China is catching up and even forging ahead in some dimensions regarding AI, and the Chinese state role in setting China's NIS has been crucial. The degree and type of openness of the innovation system remains of major importance for China's catching up in AI. China's success depends on its global access to hardware, software and AI talent. At the same time, openness has become increasingly intertwined with geopolitics. In the next section, we point to another crucial dimension of openness demonstrating that one of the major differences between the US and the Chinese tech giants is their access to data harvested in third countries.

5. Comparing Alibaba's and Tencent's Innovation Systems with those of US tech giants

The new millennium has witnessed a dramatic change in the global corporate landscape. A handful of US companies delivering digital services –Google, Amazon, Facebook, Apple and Microsoft- have grown and become financial and technological juggernauts (see Table 2). China is the only country where the US tech giants' market shares for digital services are low, while Chinese giants deliver digital services to and harvest data mainly from their domestic market. Alibaba dominates e-commerce while Tencent -through its strong position in computer games and its all-in-one app WeChat- produces a variety of digital services to the huge Chinese market.

Table 2: Market capitalization (December 31, 2019) and liquid assets (annual reports 2019)

Market value world ranking	Market value Billion US Dollar	Liquidity Billion US Dollar
No 3. Microsoft	1,203	134
No 4. Alphabet (Google)	923	119.7
No 5. Amazon	916	55
No 7. Alibaba	569	28.8
No 9. Tencent	461	29

Source: Selected companies' annual reports year 2019.

As specified in section 2.1, the evolution and performance of a lead firm's CIS reflect both internal efforts and how it creates access to external knowledge. In the next sub-section, we document selected tech giants' CIS in three respects: (1) the centrality of AI, (2) the geographical extension of their CIS -considering how tech giants engage in collaboration with universities around the world- and (3) the relevance of their respective NIS.

We proxy these traits of selected big tech CIS by analysing the privileged content and co-authors of their recent scientific publications retrieved from the Web of Science. Alibaba and Tencent only recently started their publishing activity. Hence, for each big tech, we retrieved their publications between 2014 and 2019 (see methodology in Appendix 1).

5.1 AI is at the core of tech giants' inventive activities

Alibaba and Tencent claim that AI is at the core of their business activities. Tencent (2018) states that it invests in AI for all its products and new endeavours, a strategy that the company calls "ubiquitous AI". In 2017, the MIT Technology Review ranking of the world's 50 Smartest Companies placed Tencent 8th and Alibaba 41st.[19] Table 3 presents, for each chosen tech giant, its publications' 15 most frequent multi-terms.

Table 3. Publications' most frequent multi-terms for selected tech giants (2014-2019).

Alibaba	Tencent	Google	Amazon	Microsoft
neural network	neural network	machine learning	machine learning	machine learning
recommender systems	convolutional neural network	neural networks	deep neural networks	speech recognition
reinforcement learning	social networks	speech recognition	neural network	data sets
user behavior	machine learning	Deep learning	genetic algorithm	training data
deep neural network	benchmark datasets	deep neural networks	data sets	neural networks
convolutional neural network	training data	language model	cloud computing	video coding
social networks	Neural Machine Translation	acoustic models	natural language	language model
data sets	image retrieval	approximation algorithms	speech recognition	social networks

[19] https://www.technologyreview.com/lists-tr50/what-are-the-50-smartest-companies/

natural language	big data	learning algorithms	knowledge graph	search engine
e-commerce platforms	topic model	reinforcement learning	convolutional neural network	based approach
proposed algorithm	attention mechanism	training data	acoustic model	data center
big data	representation learning	mobile devices	training data	image retrieval
search engine	computer vision	recurrent neural networks	data centers	natural language
attention mechanism	target domain	natural language	predictive models	computer vision
Online Shopping	domain adaptation	search engines	social media	deep neural networks

Source: Authors' text mining analysis based on the full corpus of scientific publications of each of the selected companies for the chosen period, extracted from Web of Science.

Table 3 is indicative of their research priorities as driven by machine learning (deep learning and neural networks) and big data. Although coming from different origins, these companies have in common that they daily collect billions of data points and focus on machine learning, the world's predominant AI technique, to process and drive (innovation) insights from big data. In terms of functional applications, tech giants' most frequent multi-terms deal with computer vision, natural language processing and speech recognition, which are AI's most frequent functional applications (World Intellectual Property Organization, 2019).

Tencent has access to multiple and diverse sources of big data. It is the world's largest gaming company favoured by China's consumption of online games. By 2015, 46% of all the data created and replicated inside China was entertainment data. Overall, WeChat is Tencent's primary source of big data. In 2020, Tencent engaged in technological cooperation with Huawei. Tencent's GameMatrix cloud game platform uses Huawei's Kunpeng processors. Besides improving this cloud business, their co-innovation laboratory will also explore collaborations in AI and augmented reality in games.[20] Tencent is also a frontrunner in facial

[20] https://www.reuters.com/article/us-tencent-huawei-games-idUSKBN21E0BV

recognition in China and provides this service to China Unicom and WeBank (partly owned by Tencent) (CBInsights, 2018).

In the case of Alibaba (2019, p. 84 and 85), the company claimed

> "we are one of the few companies in the world with a proprietary, distributed deep learning platform that has access to consumer insights across diverse businesses involving a rich variety of consumer experiences. As a result, we believe we are in a unique position to develop large-scale commercial use of artificial intelligence, or AI. We have applied various AI technologies across our digital economy to enhance the consumer experience."

An original data source that distinguishes Alibaba and Tencent from US tech giants is their online payments and credit business, developing an intertwined financial and non-financial business based on big data and AI. Together, they account for 94% of the mobile payments market in China. In comparison, Apple pay had 22 million active users in the US in the first part of 2019, while AliPay (now part of Ant Group which integrated the Alibaba Group) had 500 million and WeChat Pay (Tencent) 900 million. Alibaba and Tencent are pioneers in exploiting networks and data from other businesses to produce digital financial intelligence. The latter is used to provide financial services at a meagre cost, including millions of small vendors that do not have credit records (Frost et al., 2019).

Summing up, chosen Chinese companies have in common with their US contenders[21] that they have transformed dominant positions in digital services into a focus on the development and applications of AI in a very short period.

5.1.2. The geographical extension of tech giants' CIS

US and Chinese tech giants' CIS also present similar characteristics in terms of their respective participating organizations. Table 4 summarizes selected features of each of the chosen tech giants' CIS, proxied with scientific publications data.

[21] As shown by the authors in Rikap and Lundvall (2020).

Table 4. CIS selected features

	Alibaba	Tencent	Google	Amazon	Microsoft
Total publications until 2019 included	685	643	6447	824	17405
First year with data	2007	2005	1999	1996	1979
Publications in 2019	272	228	683	179	902
Total number of co-authoring organizations	427	366	3397	766	4025
Publications with at least 1 co-author based in China (for US tech giants) or in the US (for Chinese tech giants)	254	191	348	72	4110
Share of publications with at least 1 co-author based in China (for US tech giants) or in the US (for Chinese tech giants)	37.1%	29.7%	5.4%	8.7%	23.6%
Number of countries in publication corpus	33	26	83	53	111

Source: Authors' analysis of selected companies' complete scientific publications corpora retrieved from Web of Science.

Table 4 shows that Alibaba's and Tencent's CIS are less globalized than those of US tech giants. Nevertheless, they share publications with dozens of organizations from other countries and both companies are the last author in most of their publications (56% and 51%, respectively). In STEM disciplines, the last authorship generally refers to the coordination or supervision of the project, to reviewing and editing, and also to the study's conception and design (Larivière et al., 2021). It should be noted that last authorship figures are lower when we only look at publications that include at least one author based outside China (45% Alibaba and 37% Tencent), which is in line with these companies' relatively recent transnational expansion. Overall, while less globalized in terms of markets and data harvesting than their US counterparts, our findings put into question the belief that Chinese tech giants are still mainly national corporations (see for instance Jia et al., 2018). Many reasons contribute to explaining this result.

The global reach of tech giants' respective CIS is combined with an extreme degree of agglomeration of R&D, with innovation hubs offering them a chance to profit from concentrated resources and capabilities (Rikap and Flacher, 2020). Paunov et al. (2019) analysed OECD countries and found that digital technology patent applications are more concentrated in top cities than applications in other technology fields, in particular in the US. The US has nine of the world's top 20 cities in AI enterprises while China comes next with four. Beijing leads the ranking with 395 AI enterprises followed by San Francisco with 287 (China Institute for Science and Technology Policy at Tsinghua University, 2018).

Alibaba and Tencent have globalized their R&D facilities, settling in innovation hubs. Only two of Alibaba's new AI centres (called DAMO Academy) are in China. There are three in the US (Seattle, Sunnyvale and New York), one in Israel and one in Singapore.[22] Alibaba claims that the DAMO Academy "aims to integrate science with industry and speed up information exchange" (Alibaba, 2019). These centres are close to leading research universities, looking both to profit from their research capabilities and attract talent.[23] Tencent has also opened an AI research centre in Seattle.[24] Furthermore, among the employees working in Chinese tech giants' US AI laboratories, there are not only US elite university graduates but also former executives and scientists from Microsoft.[25]

While US tech giants have been active in acquiring AI start-ups (World Intellectual Property Organization, 2019), Alibaba's and Tencent's globalization strategies privilege purchasing equity stakes. According to Crunchbase, by June 2021 Tencent had acquired 18 companies, but invested in 582.[26] Tencent's investments include equity in Snapchat and, in 2018, an equity swap with Spotify.[27] Since the Covid-19 pandemic, Tencent has taken advantage of some

[22] https://damo.alibaba.com/about/
[23] https://techcrunch.com/2017/10/10/alibaba-group-will-invest-15b-into-a-new-global-research-and-development-program/
[24] https://techcrunch.com/2017/04/28/tencent-to-open-ai-research-center-in-seattle/?_ga=2.127708877.1164454910.1592757734-700995395.1592226319
[25] https://analyticsindiamag.com/google-hiring-ai-workforce-baidus-alibabas-backyard/
[26] https://www.crunchbase.com/organization/tencent
[27] https://techcrunch.com/2018/02/28/tencent-music-spotify/

foreign companies' falling valuation and acquired Funcom, a Norwegian game developer. It also took a stake in Yager, a German developer, and poured capital into multiple fintech start-ups.[28]

Alibaba’s equity investment strategy was often motivated by seeking access to advanced technologies, such as the encryption technology firm V-Key headquartered in Singapore and the Israeli company ThetaRay, which specialized in financial network security. This strategy also included firms from the US, Canada and India (Jia et al., 2018). Alibaba's recent acquisitions include the US start-up MagicLeap specialized in AR/VR technologies. Overall, it has acquired 34 companies and invested in 227.[29]

Another source of foreign knowledge for Alibaba and Tencent is the open-source community, whose main online platforms engage developers from around the world, as is particularly the case of GitHub, a community of over 44 million developers from 41 countries, led by the US and China considering the number of contributors.[30] Alibaba (2018) claimed to be contributing to more than 100 projects by March 2017; its open-source projects in GitHub were, by 2020, the most active among those put in open source by Chinese enterprises (X-lab, 2020). A similar number of projects had been open sourced by Tencent by early 2020 on topics like cloud computing, big data, AI healthcare and network security.[31]

5.3 A glimpse of the tech giants’ CIS using co-authorship as an indicator

Table 4 provided evidence of how Alibaba and Tencent have organized CIS with global (or at least beyond national) outreach. Nonetheless, China’s NIS played an important role in these

[28] https://www.ft.com/content/844ed28c-8074-4856-bde0-20f3bf4cd8f0
[29] https://www.crunchbase.com/organization/alibaba
[30] Retrieved from https://octoverse.github.com/ last access November 23, 2020.
[31] https://www.tencent.com/en-us/articles/2201019.html

companies' emergence as tech giants. The privileged access to Chinese data is fundamental for their success. Sourcing knowledge from domestic organisations is another major factor.

Table 5 presents each company's top ten co-authoring organizations between 2014 and 2019. It indicates that tech giants most frequently draw upon the science base of their own NIS.

Table 5. Top Co-authors between 2014 and 2019 included

Alibaba	Tencent	Google	Amazon	Microsoft
University of Sci & Tech of China	Chinese academy of science	University of California	University of California	University of California
Chinese academy of science	Chinese University of Hong Kong	Stanford University	Microsoft	University of Washington
Zhejiang University	Tsinghua University	Microsoft	University of Washington	University of Sci & Tech of China
Tsinghua University	Peking University	MIT	Google	MIT
Peking University	Shanghai Jiao Tong University	Harvard	IBM	Tsinghua University
Shanghai Jiao Tong University	Sun Yat-sen University	Carnegie Mellon University	Georgia Inst of Technology	University of London
Microsoft	Zhejiang University	University of Illinois	Carnegie Mellon University	Carnegie Mellon University
Fudan University	Harbin Institute of Technology	University of Washington	University of Texas	Google
Nanyang Technological University	Beihang University	IBM	MIT	Stanford University
Nanjing University	Nanyang Technological University	New York University	Indian Inst of Technology	ETH Zurich

Source: Authors' analysis of selected companies' full corpora of scientific publications for the selected period extracted from Web of Science.

Google, Amazon and Microsoft share part of the same US universities as most frequent co-authors, with the University of California ranking always first. Likewise, Tencent and Alibaba rely, in part, on the same Chinese universities, the Chinese Academy of Science and a Singaporean university. Microsoft has the most diverse network. It includes two Chinese and two European universities in its top ten list.

Unsurprisingly, Zhejiang University is among Alibaba's most frequent co-authors. In 2018, Alibaba released a video-editing tool that uses AI to generate videos about products on Taobao. Called Aliwood, it was co-developed with Zhejiang University.[32] In 2020, both organizations signed a framework agreement on comprehensive strategic cooperation. It included the construction of Alibaba-Zhejiang University Joint Institute of Frontier Technologies[33] and, in 2021, they launched the Joint Research Institute of Future Digital Health.[34] Despite this institutionalized collaboration, at least until May 2021, Alibaba and Zhejiang University had not applied for any joint patents. This finding is in line with our previous research results that show that tech giants do not usually share the property of R&D results from their CIS (Rikap and Lundvall, 2020).

Table 5 also provides evidence of frequent technological cooperation between Google, Amazon and Microsoft, as well as with IBM for the cases of Amazon and Google. Of greater relevance in terms of China's AI catching up is the technological cooperation between Alibaba and Microsoft. Overall, Alibaba and Tencent published relatively more frequently with US co-authors than US tech giants with Chinese organizations (see Table 4). Nevertheless, Microsoft's total number of co-authored publications with at least one Chinese organization is remarkable and speaks of this company's long history in China. It is the US giant with the most significant presence in China and one of the leading companies in terms of AI patenting in this country[35].

Summing up, our findings point to tech giants' CIS as global systems with strong roots in their respective NIS. This is true not only for Alibaba and Tencent but also for US tech giants. Yet, we found that tech giants, Alibaba and Tencent included, geographically build their CIS way beyond their home countries. Alibaba and Tencent have overcome China's AI weaknesses by

[32] https://www.alizila.com/alibaba-releases-new-ai-video-editor-aliwood/
[33] https://www.zju.edu.cn/english/2020/0331/c19573a2019025/page.htm
[34] https://www.zju.edu.cn/english/2021/0315/c19573a2266874/page.htm
[35] https://www.lexology.com/library/detail.aspx?g=62d03fd9-091f-4416-9470-f7ebea201efa

importing a solution or accessing it abroad by settling R&D facilities in foreign innovation hubs. Alibaba and Tencent import AI-talent (mostly Chinese people but trained in the US) or access it by organising research in the US and other innovation hubs and by co-authoring with foreign universities.

6. On the co-evolution of National and Corporate Systems of Innovation

This article is work in progress, building on Chris Freeman's research and legacy with the ultimate aim to understand world development as the outcome of a co-evolution between NIS and CIS. This intention should be seen on the historical backdrop of the formation of the US and Chinese tech giants and the growing geopolitical tension between those countries. The interplay between tech giants and their respective state is based both on mutual reinforcements and clashes of power.

The configuration of US and Chinese tech giants' CIS confirms that they all give priority to AI and that they harvest knowledge primarily from their respective home country's top universities. They gather their strength from their own NIS and use it to expand abroad and harvest both data and knowledge beyond national borders. Nonetheless, while tech giants are in the midst of the confrontation between the US and Chinese states, and even involved in shaping techno-nationalist strategies, they remain dependent on access to knowledge from activities in the opposite country.

Alibaba and Tencent have built their strength in AI not only based on the R&D of Chinese universities and public research organizations but also on privileged access to the Chinese market for digital services and data. Within China's NIS characteristics, the highly developed telecom infrastructure and widespread use of mobile phones together with the digital firewall were prerequisites for the formation of Chinese tech giants. Furthermore, according to

Jacobides et al. (2021), the state encouraged its tech companies to drive AI adoption and innovation in China. Nevertheless, in order to ascertain access to markets, data and technologies abroad, these giants operate with some degree of autonomy in relation to the state. Indeed, in areas where China's NIS is weak, our findings provide evidence of Alibaba and Tencent seeking knowledge and using hardware from abroad.

The other way around, the US and Chinese states have become to some extent dependent on the global success of nationally rooted tech giants, both for the profits (including financial rents) they harvest abroad and for their role in developing and applying AI regarded as a strategic technology. Yet, US and Chinese tech giants' strong positions in their respective domestic markets and their capacity to dictate their own rules and norms in the digital world raise states' concerns.

Tech giants are among the world's largest corporations and their corporate power challenges states. The US Congress (2020) recently investigated (and subsequently sued) US tech giants' for excessive market power. However, it has recently been the Chinese state who has gone the furthest in its attempt to regulate its tech giants.

Just before Ant Group's IPO in Shanghai, the Chinese government announced antitrust regulations for digital companies halting the IPO.[36] The Chinese state then introduced further requirements to Alibaba and Tencent, closer to those that commercial banks -which are SOEs- must comply with. Furthermore, the People's Bank of China wants Ant Group to turn over its credit data to a state-controlled credit scoring company that will manage data as a public good.[37] To remain in control of its domestic financial markets, the Chinese state intervened favouring its SOEs over private tech giants. These and recent events outline the ongoing clashes of power between tech giants and the Chinese state, including the Xi Jinping's call for stronger regulation

[36] https://www.ft.com/content/1a4a5001-6411-45fa-967c-0fd71ba9300b
[37] https://www.ft.com/content/1651bc67-4112-4ce5-bf7a-d4ad7039e7c7

of high incomes and the promotion of common prosperity, which has triggered Alibaba, Tencent and other giants to pledge donations for such aim.

Another point of conflict in the co-evolution of these powerful actors concerns corporate governance, given the significant foreign presence in Alibaba's and Tencent's shareholding structure and the state's recent aims to regulate foreign IPOs.[38] The system that allows foreign capital to own Chinese companies' shares through offshore holding companies, called the Variable Interest Entity (VIE) model, has become a direct channel used by transnational capital to control Chinese digital companies (Shen, 2021; Wójcik and Camilleri, 2015). However, being the main stockowner does not directly translate into controlling Chinese corporations as illustrated by Jack Ma's decision to spin-off Alipay in 2011 as a mainly Chinese own company to assure the Chinese state's approval to operate in China, regardless of the accusations and discomfort of Yahoo and Softbank, back then Alibaba's main shareholder.[39] The VIE model is another example of the complexities of China's openness strategy. It was established in the early 2000s and the state implicitly agreed on tech company's raising foreign capital ownership (Shen, 2021) until recently, when China Securities Regulatory Commission was given the task to review Chinese IPO plans abroad that used the VIE model.[40]

Overall, we can argue that China's catching up in AI reflects a process of co-evolution between China's NIS and Alibaba's and Tencent's CIS. We expect that China's attempts to overcome current weaknesses of its NIS will be a major factor determining the future strength of the

[38] In line with the globalisation of corporate governance (Fichtner and Heemskerk, 2020), by early 2021, Alibaba's top shareholder was the Japanese multinational holding Softbank, with around 25%. Softbank also owns substantial shares in other Chinese tech companies like Didi and ByteDance. Alibaba's second and third-largest stockowners are its co-founders, Joseph Tsai and Jack Ma in that order. After them, leading asset managers from the US and the United Kingdom followed (T. Rowe Price, Vanguard Group, BlackRock, Baillie Gifford and State Street). Together, the latter owned 10% of the company's shares. The share of Tencent's stocks in foreign hands is even bigger. Although its founder, chairman and CEO, Ma Huateng, held 8% of the company's stocks by that same date, Tencent's largest shareholder is the South African multinational Naspers (31%). After these two major shareholders, three US-based asset managers followed: Vanguard (2%), BlackRock (1%) and Capital Research (1%) (Fernández et al., 2020).

[39] https://www.ft.com/content/40a66dd2-b9ec-11e0-8171-00144feabdc0

[40] https://www.reuters.com/business/how-chinese-clampdown-will-target-offshore-listings-2021-07-08/

Chinese tech giants and China's catching up in AI. While the specific efforts to compensate for current weaknesses in AI will matter, equally important will be how the interaction between knowledge institutions and industry and the innovation capabilities of the majority of enterprises develop in the future.[41] Moreover, recent regulatory interventions by the Chinese government in industries where AI and data play an important role, as well as our findings, highlight the formative role of government policies in China's AI catching-up. These are factors that will impact the capacity to absorb and use AI in new fields such as health, education, intelligent cities and transport.

7. Conclusions

In this contribution, we started from Christopher Freeman's understanding of technological revolutions as opening up for changes in the world economic leadership. It is interesting to note that Freeman (2002) anticipated that the US dominance may be a temporal phenomenon:

> At the present time (late 1990s) the United States appears to have enormous advantages compared with its principal competitors. It is impossible to predict however how long these advantages can be retained despite the tightening of intellectual property restrictions. Very many countries have rapidly growing young software firms including Eastern Europe, as well as Eastern Asia, Latin America and countries with strong English language capability, such as India. Moreover, political and social events may predominate over more narrow technological and economic factors (Freeman, 2002, p. 208)

He also pointed toward a possible future where the growing importance of global corporate innovation networks may challenge the predominance of NIS:

> This paper has concentrated on developments at the national level in the belief that the major phenomena of forging ahead, catch-up and falling behind in 19th and the 20th centuries can most plausibly be explained in terms of national systems, albeit in an international context and recognising uneven development at the sub-

[41] In this respect, China's Artificial Intelligence Industry Alliance constitutes an initiative to be further analysed in the future. Launched in 2017, it is integrated by over 550 members, mostly firms -both Chinese and foreign- but including 31 academic institutions and 21 government entities. Alibaba, Tencent, the other Chinese tech giants and several SOEs are vice chairs of its board (Luong and Arnold, 2021).

> national level. All of this may change in the 21st century. In particular, the capacity to use information and communication technology will probably be a decisive factor in world competition and this in turn will lead to the dominance of firms and networks with capability in service activities (Freeman, 2002, p. 209).

His intuition anticipated the emergence of tech giants organising global corporate innovation systems that challenge NIS. Nevertheless, globalisation has sharpened rather than weakened the focus on the performance of the NIS, especially in the US and China. The rise of China, including its attempt to become a world leader in strategic technologies, has reinforced a new type of techno-nationalism, which threatens to divide the world into two separate spheres of knowledge production and use. The final outcome will reflect a combination of geopolitical actions and innovation processes in the US and China.

These are ongoing developments shaping global innovation processes and conditioning national development strategies in the rest of the world, where digitalization has revealed scale disadvantages for small and medium-sized NIS delivering data to tech giants. If we are right in assuming that AI is a transformative technology, it is a major problem that it tends to become concentrated geographically and that the path-breaking AI algorithms are intangible assets in the hands of tech giants, from Google's search engine and Amazon's e-commerce prediction model to those developed by Google's DeepMind and Microsoft-backed OpenAI. Within the European Union, member states have been forced to act collectively to confront tech giants. We might see similar developments toward economic integration and common AI strategies in Latin America and Africa.

But, for all these regions, it remains unclear whether, regardless of the size of their efforts, they will catch up with the current (corporate and national) world leaders (Rikap and Lundvall, 2020). Tech giants are in a privileged position when it comes to harvesting the fruits from conventional STI-policy, such as investments in education, science and infrastructure. The example of China supports Freeman's argument that catching up requires a state with the capacity to build a strong domestic knowledge base, strong enough to negotiate the openness of the national – or supra-national – innovation system.

Further research is needed concerning how systems' coevolution in China and the US shape world development. What we expect to have made clear is that Chris Freeman's legacy is a stimulating starting point for advancing our knowledge on how radical technical changes impact global geopolitics and the role that (national and corporate) innovation systems at different levels play in these reconfigurations.

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Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix

We retrieved selected tech giants' scientific publications between 2014 and 2019 from the Web of Science. All the data were processed with the CorText platform, which is an integrated application dedicated to the processing and treatment of various types of datasets.[42] We used it to perform a lexical analysis on the content of each corporation's scientific publications corpus.

For each corpus (company), we used text-mining techniques to extract the top 1000 multi-terms of up to five words restricted to terms that appeared at least once in three different publications. Monograms were excluded and each list was refined following an in-depth cleaning to avoid words not related to the field and whose frequency responds to either their grammatical function ("and", "or", etc.) or the level of grammaticalization within the scientific publications' genre (such as "article studies", "best known solution", etc.), respectively. After this cleaning, we built lists with the 15 most frequent multi-terms for each corporation's corpus.

We also retrieved each corporations' list of most frequent co-authoring organizations as well as other features of their publications' corpus. Although the Web of Science presents an already cleaned database, affiliations frequently appeared spelled differently. To build a unified list, thus assuring that each institution appeared under only one single name, we followed the

[42] It can be accessed online at https://www.cortext.net/

methodology presented in Testoni et al. (2021) for corpora cleaning. To unify the names of private firm affiliations, we worked with corporate trees as provided by Derwent Innovation.