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Should we fear China’s brave new digital world ?

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NationalBank
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Introduction

China is rapidly becoming a digital powerhouse and has high ambitions for technological leadership, rivalling and ultimately overtaking the US and the EU. The importance of a strong digital economy can hardly be overstated. In today's knowledge economy, digital infrastructure and capabilities increasingly determine a country's competitive position, not only in the ICT sector but in nearly all sectors, including defence, as the latter become increasingly integrated with ICT. Moreover, being a first-mover on digital innovation opens up opportunities for standard-setting, another area where China wants to play a greater role.

The US and the EU are concerned about losing their competitive edge. They also want to limit their strategic dependence on China for key technologies and stop sensitive data and technologies from falling into the hands of the Chinese authorities. They increasingly resort to counter- and proactive measures to avoid such scenarios.

This article starts by taking a closer look at the general characteristics of China's digital economy. Some of its strengths and weaknesses are further illustrated by two relevant case studies. First, we show that China is a front runner in the digitalisation of financial services (digital payment systems, new forms of credit) and the development of its central bank digital currency. Conversely, in a second case study, we find that China has been much less successful at mastering the cutting-edge technologies needed to produce the most advanced semiconductors, leaving China dependent on foreign suppliers of such critical technologies. In the second part of the article, we look at China's unique policy approach towards fostering innovation-driven economic growth and president Xi Jinping's vision for the digital economy. The third and final part gives an overview of the most important policy actions undertaken by the US and the EU in response to China's rise as a digital power.

1. China's digital economy in comparative perspective and selected case studies

1.1 Broader picture

Since joining the World Trade Organization (WTO) in 2001, China has quickly transformed itself into the world's primary manufacturing powerhouse for a wide range of ICT products and consumer electronics. Several

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internationally renowned Chinese giants, such as Alibaba, Tencent and Huawei, have also firmly established the country as one of the leading digital innovators. China's digital sector can be considered as the standard bearer of the country's broader ambition to become a global technological power. A useful starting point is to put the size of China's digital economy into perspective and look at how its size compares to that of advanced economies. Next, we assess the role of China as a digital innovator based on patterns in research and development (R&D) spending and intellectual property (IP) filings.

1.1.1 Size of the digital economy in China

A precise definition of the digital economy is complicated by its rapidly evolving boundaries. In a report commissioned by the G20, the OECD (2020, p. 5) proposed the following comprehensive definition: "The Digital Economy incorporates all economic activity reliant on, or significantly enhanced by the use of digital inputs, including digital technologies, digital infrastructure, digital services and data. It refers to all producers and consumers, including government, that are utilising these digital inputs in their economic activities". Based on this definition, the OECD makes a distinction between a "narrow" and "broad" concept of the digital economy. Both are part of the "digital society", which also encompasses other aspects of digitalisation, e.g., digital skills and digitalised interactions not incorporated in GDP.

The narrow definition refers to the size of the ICT sector only, including telecommunication, internet, IT services, hardware and software, etc. (Zhang and Chen, 2019). A rough measure of its size can be obtained using the system of national accounts. Following a simplified methodology[1] developed by the OECD, we estimate the size of China's (narrowly defined) digital economy at 5.5 % of GDP in 2018 (Chart 1, left panel). This makes China an average performer, lagging behind the global front runners (South Korea, the US and Sweden) but ahead of the weaker performers in the euro area (Italy, Belgium). This ranking needs to be interpreted with caution though. Some more recent digital activities that cannot easily be captured using the standard industrial classifications are not incorporated in the digital economy measure. Examples of such omissions include the value added created by digital platforms, and services enabled by such platforms (including e-commerce), digital content and cloud computing. This introduces a downward bias, particularly for countries which are leaders in those areas (China, UK, South Korea and US).

The relatively low value added generated by China's ICT manufacturing sector may come as a surprise, considering its status as a manufacturing powerhouse and leading exporter of ICT goods. The difference compared to South Korea, in particular, is striking. However, China is more specialised in the production and assembly segments of the global value chain for ICT products, characterised by a low value added (Garcia-Herrero and Xu, 2018; Buysse, Essers and Vincent, 2018), whereas South Korea specialises in activities with a much higher value added, such as the design of ICT goods. This difference is particularly important for semiconductors, as we will discuss in detail in section 1.3. Another factor holding back the relative size of China's digital economy is the significant variation in the degree of digitalisation across provinces, reflecting large disparities in their economic development (Zhang and Chen, 2019). While the development of China's richest coastal provinces is quite advanced, China is still classified as an emerging economy overall, which implies that the importance of its digital sector should not be underestimated.

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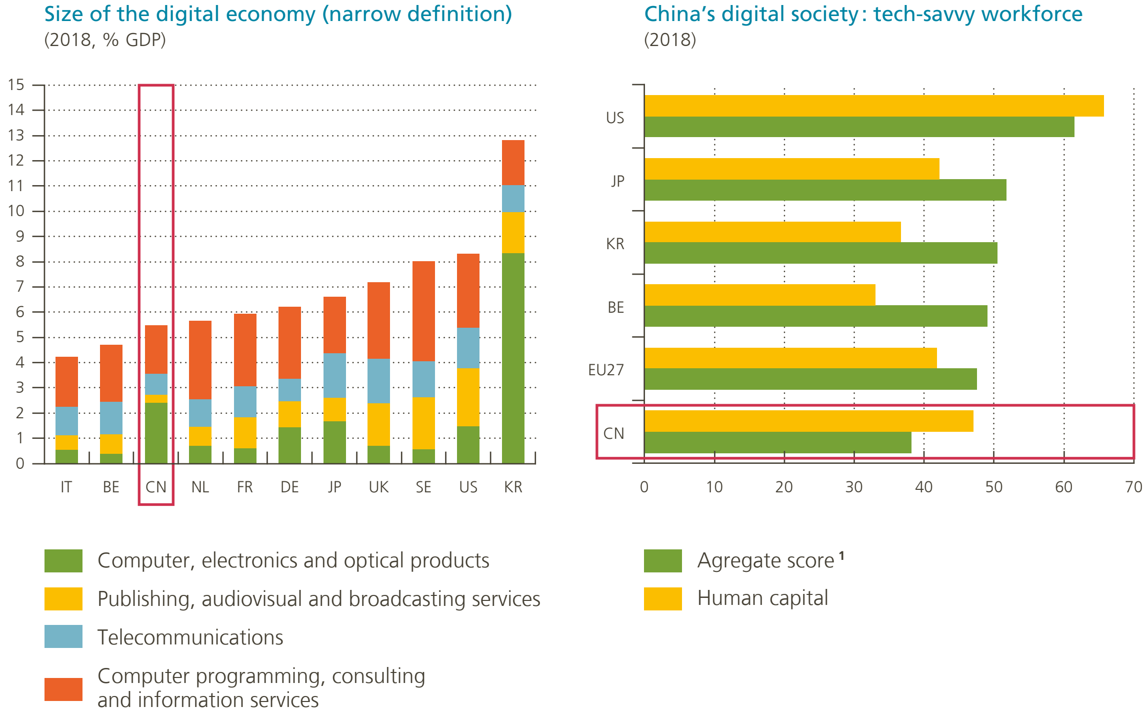
[1] Information industries cover the following two-digit Industrial Classification of All Economic Activities (ISIC) Rev.4 divisions: Computer, electronic and optical products (26); Publishing, audiovisual and broadcasting (58 to 60); Telecommunications (61); and IT and other information services (62, 63). Data were retrieved from the OECD's TiVA (Trade in Value Added) database, which contains information up till 2018, on 13 April 2022.

Chart 1

China's digital economy and society: not (yet) among the front runners



Size of the digital economy (narrow definition)
(2018, % GDP)

China's digital society: tech-savvy workforce
(2018)

Sources: EC, OECD (TiVA).

1 Aggregate score is a weighted average of five main dimensions (connectivity, human capital, use of digital services, integration of digital technology, and digital public services), each of which is in turn a weighted average of several indicators.

The broad definition of the digital economy covers both the ICT sector and parts of traditional sectors that are significantly enhanced by the use of digital inputs, which include digital infrastructure, equipment, software and data. The China Academy of Information and Communications Technology (CAICT) applies a methodology[1] based on this broad definition to calculate the size of China's (broadly defined) digital economy. According to CAICT's (2020) latest report, the digital economy in China accounted for 36.2 % of total GDP in 2019, against only 15.2 % in 2008. Reliable international comparisons are not available, but based on its own calculations, the CAICT believes that China is still well behind the global leaders. It also finds that the growth of China's digital economy is mainly driven by the digitalisation of traditional sectors. The services sector is the most digitalised (e.g., financial services and e-government) while the industrial sector lags due to a still limited take-up of industrial robots.

The performance of the digital society is often captured by a composite index which is constructed as a weighted average of a range of internationally available indicators that measure various aspects of digitalisation. Examples of such indices include the Digital Adoption Index from the World Bank, or the International Digital Economy and Society Index (I-DESI) from the European Commission. The latter is used by the Commission to benchmark the digital performance of EU member states against the major non-EU countries. I-DESI uses 24 indicators classified under five headings[2] and uses a weighting system to rank the countries according to their global score.

[1] This methodology calculates the digital capital stock and non-digital capital stock separately in the total economy and adds the contribution of the digital capital stock to the size of the digital economy.

[2] The five categories considered are (1) connectivity, (2) human capital, (3) use of internet services, (4) integration of digital technology, and (5) digital public services.

According to the latest I-DESI (EC, 2020a), covering the years 2015-2018, China still ranked below the EU27 average and well below the US (Chart 1, right panel). However, due to its high number of graduates in ICT programmes, China outperforms the EU27, Japan and South Korea on the I-DESI's human capital dimension. Moreover, due to the time lag in the data, China's current leadership in 5G and its rapid roll-out of 5G networks (Grünberg and Wessling, 2021) are not yet reflected in its global score.

1.1.2 China is emerging as an important innovator in the digital economy

In line with its ambition to become a technological leader, China has steadily increased its spending on R&D over the last decades. According to China's National Bureau of Statistics, R&D spending amounted to 2.4 % of GDP in 2021, compared to only 0.7 % in the early 1990s, though it is still lagging somewhat behind current technological leaders such as the US, Japan, South Korea and Germany, which are spending 3 % of GDP or more on R&D according to OECD data.[1] Nonetheless, China's performance is impressive when compared to other emerging economies. With only 6 % of total R&D spending flowing into fundamental scientific research, China's focus is mainly on applied research leading to incremental innovation. However, fundamental research has been found to be the key driver of technological progress and productivity growth. Although the magnitude of scientific knowledge spillovers from advanced to emerging economies such as China is particularly high (IMF, 2021), China needs to produce more fundamental scientific knowledge itself if it wants to reduce its dependence on advanced economies, a necessary condition to become a global leader in breakthrough innovations.

Rising R&D intensity can partly explain China's explosive growth in IP filings over the last decade (Eberhardt *et al.*, 2017). Growth figures for IP filings by category reveal that "utility models" have been the biggest driver of the explosive trend. Such utility models provide protection for minor inventions or minor improvements to existing products. Compared with patents, utility model systems require compliance with less stringent requirements, have simpler procedures and offer shorter-term protection. The declining ratio of invention patents to utility models over time (Chart 2, left panel) is therefore an indication that the increase in patent quality has not been proportionate to the rise in quantity (Prud'homme and Zhang, 2017), and again illustrates China's focus on applied research. While utility models have contributed to productivity improvements in China in its earlier stages of technological development, they exhibit declining returns as their numbers increase. This implies a risk of creating path dependence on low-quality inventions. By way of comparison, the ratio of invention patents to utility models increased in South Korea during its transition to a more sophisticated stage of technological development.

Recent empirical evidence suggests that patent subsidies, introduced by local governments in virtually all Chinese provinces from 1999 onwards, have also played an important role in explaining the explosive growth of Chinese patents (Eberhardt *et al.*, 2017). Local government support measures include exemptions from patent application and/or examination fees. In addition, China's patent system traditionally put more emphasis on diffusion than on protection of intellectual property (Molnar and Xu, 2019). In combination with generous subsidies, this system has favoured incremental innovation, as evidenced by the high number of utility model patent applications, and fostered technology diffusion to smaller firms. However, stronger protection of intellectual property rights (IPR) would encourage Chinese inventors to invest in real innovation and register their inventions. The Chinese government issued guidelines in 2019 to strengthen IPR protection (OECD, 2022).

Another indicator of patent quality is the rate of patenting abroad, the logic behind this being that firms are only willing to pay for the fees required to protect patents in other countries if they believe their inventions are valuable. In 2020, only 6.7 % of all applications by Chinese residents were filed abroad (WIPO, 2021). In contrast, for Japan and the US filings abroad accounted for around 45 % of all applications. Although Chinese firms might be more focused on the very large domestic market and, to some extent, feel less incentivised to protect their IP abroad, it is more likely that many Chinese patent applications would not pass international evaluation because of the lower quality of the patents.

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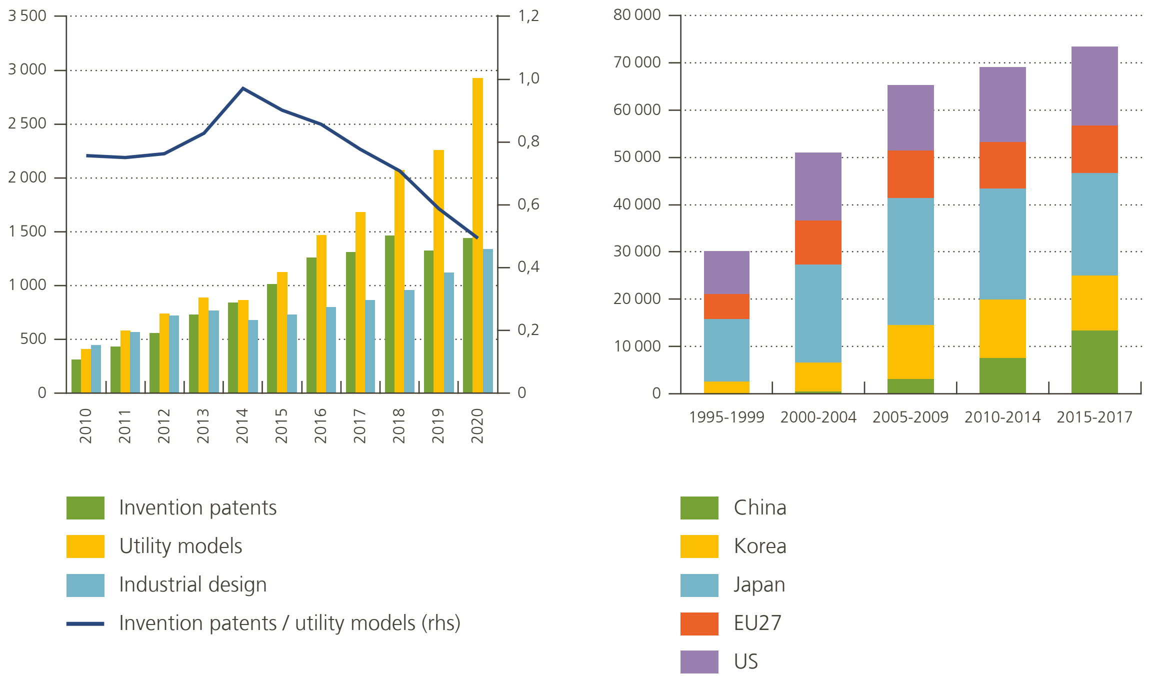
[1] OECD Main Science and Technology Indicators.

Chart 2

Despite the explosion in intellectual property filings in China, international relevance of patents is still limited to a few sectors and superstar corporations



Intellectual property filings[1] by Chinese residents
(in thousands)

Number of patents[2] in ICT-sector

Sources: OECD (STI), WIPO.

1 Applications filed domestically and abroad.

2 IP5 patent families are patents filed in at least two offices worldwide, including one of the five largest IP offices: the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, the US Patent and Trademark Office and the National Intellectual Property Administration of the People's Republic of China. Triadic patent family counts are attributed to the country of residence of the inventor and to the date when the patent was first registered. Patents in ICT are identified using the list of International Patent Classification codes.

Notwithstanding the above caveats, China has emerged on the international scene as a new key ICT innovator. In fact, internationally registered patents by Chinese residents are concentrated in the hands of a small number of superstar firms, many of them operating in the ICT sector (Dernis *et al.*, 2019; Molnar and Xu, 2019). Well-known national champions include Huawei, ZTE and Lenovo. The concept of "patent families" – a grouping of related patent applications filed in two or more jurisdictions to protect the same invention – is often used to measure the international relevance of innovations. Patent families aim to capture the number of unique inventions by excluding the double counting that results from the fact that applicants often file patent applications for the same invention in multiple jurisdictions. The number of ICT-related patent families that can be attributed to China has grown steadily between 2005 and 2016, surpassing the EU27 in this area (Chart 2, right panel).

Finally, forward patent citations, i.e., the citations in a patent referring to previously filed patents, are another, more sophisticated indicator of patent quality. Like citations in academic literature, patent citations signal work that serves as the basis for subsequent work. Applying this methodology to Chinese invention patents is challenging, one reason being that domestic and self-citations suffer from an upward bias in China (Huang *et al.*, 2021). Boeing and Müller (2015) construct an internationally comparable index based on foreign citations and find that Chinese patent applications achieve only a third of the quality level of other international patent applications (US, South Korea, Germany, and Japan). In addition, Chinese patent quality appears to be decreasing over time. More recent research by Fang *et al.* (2021) looks at China's patent quality relative to the US only, using a sample of dual-listed patents registered in both the US and China's patent office and originating in China or the US. Standardised forward citations indicate that the US patents' average quality is twice as high as that of the Chinese patents. In contrast to Boeing and Müller (2015), however, Fang *et al.* (2021) find that the relative quality of Chinese patents to US ones is increasing over time.

1.2 Case study: Chinese fintech / BigTech credit and e-CNY

1.2.1 Emergence of digital payment systems and new forms of credit in China

China is widely seen as a front runner in the development of digital payment platforms. Given the lack of financial services that are considered standard in the West – such as online banking, credit cards[1] and nationwide accepted debit cards – China's emerging internet companies in the early years 2000 were forced to search for alternative person-to-person payment methods (Chorzempa, 2018a). Non-bank payment systems really took off with the democratisation of smartphones, the rapid expansion of mobile internet access and the growing importance of e-commerce in retail sales around 2010 (Zhu, 2021). China's digital payment system is built on digital wallets (Turrin, 2021). The wallet is funded either by transfer from another digital wallet, or directly by linking it to a bank account and transmitting funds from there. A unique feature is that it requires only one party (usually the customer) to be connected to the internet in order to proceed with the transaction, facilitating adoption by offline businesses and even tiny street vendors (Chorzempa, 2018a). Money transfers between digital wallets are processed via the mobile network using smartphone apps developed by Chinese technology firms and do not involve any further intermediation by traditional banks.

China's mobile payment system is dominated by two large payment platforms: Alipay, linked to China's largest e-commerce firm Alibaba (both are part of Ant Group), and WeChat Pay, linked to China's social media giant Tencent. The two platforms together command more than 90 % of the mobile payment market. The success of these payment platforms is the result of a symbiotic relationship with the parent firms' core businesses, which provided a strong incentive to become early movers in the development of their payment business (Turrin, 2021). China is the world's largest e-commerce market with 29 % of retail sales generated online (JPMorgan, 2020). In 2019, 58 % of e-commerce transactions were paid by digital wallet, versus 22 % by bank cards and 14 % by bank transfers (Chart 3, left panel). While digital applications are also becoming a common payment method in e-commerce in some advanced economies, like the US and UK, other payment methods intermediated by banks (cards, transfers, debit and invoices) still predominate.

China is also a front runner in the provision of credit facilitated by online platforms rather than by traditional banks or non-bank lending companies. The Bank for International Settlements (Cornelli *et al.*, 2020) refers to the latter as "debt-based alternative finance", which covers two types of credit models. Fintech credit models are built around decentralised platforms that match individual lenders with borrowers or projects in a market framework. Such platforms help to solve problems of asymmetric information, both through their screening practices and by providing investors with information on the risk of a loan and other borrower characteristics. By contrast, BigTech credit is credit provided by a technology firm for which lending represents only a small part of their wide range of business activities. By exploiting large datasets collected from their existing (e-commerce / social media) platforms, and with the adoption of cloud computing and artificial intelligence, these firms can quickly make informed decisions on loan applications. Their access to large volumes of information, typically of a non-financial nature, may give them a comparative advantage over traditional banks in assessing the default risk of loan applicants with no credit history.

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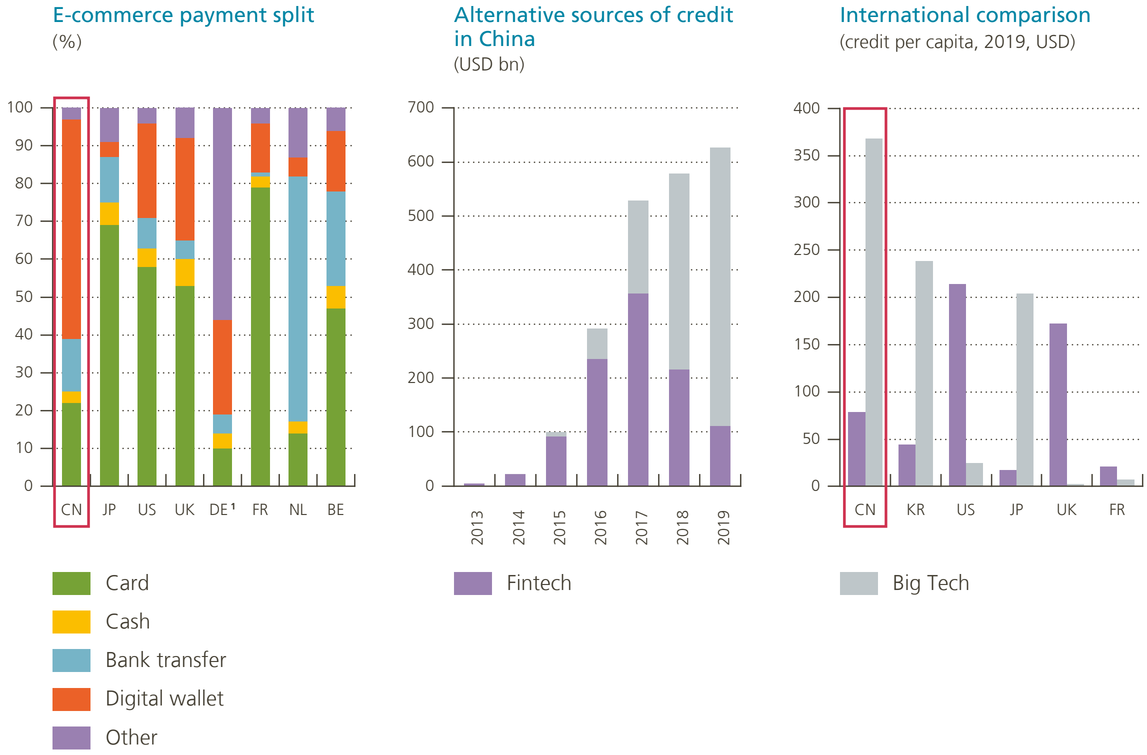
[1] International bank card companies like Visa and Mastercard were not allowed to enter the Chinese market until 2018.

Chart 3

China is a front runner in digital payment platforms, fintech and BigTech credit



E-commerce payment split
(%)

Alternative sources of credit in China
(USD bn)

International comparison
(credit per capita, 2019, USD)

Sources: BIS, JPMorgan.

1 In Germany, direct debit and open invoice are popular payment methods for e-commerce, representing respectively 20 % and 28 % of all payments.

The Chinese government supported the development of the two alternative credit models in their early stages, allowing them to operate in a relatively accommodating regulatory environment (Zhu, 2021). Their ability to extend financial services to a large part of China's population that does not have a traditional credit history and still lives in rural areas with limited access to banks fostered financial inclusion, which also happened to be an objective of the government.

The volume of fintech credit experienced exponential growth in China between 2013 – the first year for which data are available – and 2017 (Chart 3, middle panel), driven by the proliferation of private peer-to-peer (P2P) platforms. Without proper supervision, it turned out that many of these platforms were run as Ponzi schemes, plagued by fraudulent and misleading practices (Turrin, 2021). This forced the government to step in and gradually tighten regulation, leading to a rising number of defaults among P2P platforms from 2016 onwards. From their peak of 3600 platforms in November 2015, the P2P sector had completely vanished by the end of 2020 (Chart 3, middle panel).

BigTech credit on the other hand continued to boom. According to Cornelli *et al.* (2020), BigTech companies like the Ant Group, Tencent, China's internet search engine Baidu and China's second largest e-commerce firm JD.com together lent an equivalent of USD 516 billion in 2019 in the form of micro-loans to a wide range of borrowers including consumers; small, medium-sized and micro-enterprises; farmers and students. This makes China the world's largest market for BigTech credit, followed by Japan and South Korea (Chart 3, right panel). In contrast, the US and the UK are the largest markets for fintech credit. And in most European countries, alternative finance is still in its infancy.

China's BigTech firms have found it harder to export their successful domestic payment platforms and financial services to other countries. Ant Group has been the most proactive in pursuing a strategy of international expansion through foreign direct investments and partnerships with local e-wallet and/or payment systems, which helped it to successfully establish a presence in South-east Asia (Zhu, 2021). However, data security concerns[1] have hampered Ant Group's expansion strategy into the US and European markets. The company's presence in those markets has been limited to partnerships with local banks to ensure that Chinese citizens travelling abroad can use their e-wallets for payments on their terminals. Finally, the export of BigTech financial services faces even stiffer barriers against entry into Western markets due to bank licensing requirements.

1.2.2 China's central bank digital currency: the e-CNY

China's position as a front runner in digital payments has not been confined to the private sector. The People's Bank of China (PBOC) has joined the financial innovation game with its plans to launch a central bank digital currency (CBDC)[2]: the digital renminbi or e-yuan/e-CNY. Today, China is one of the most advanced in rolling out such CBDC plans. Most other major economies are still in an early exploratory stage where the advantages and disadvantages of different possible CBDC designs are being deliberated (Chart 4).

As long ago as 2014, following a Chinese demand-driven bitcoin price boom, the PBOC took the first steps towards its own CBDC by setting up a dedicated task force. Chinese policymakers hoped that putting in place a CBDC would help to control the capital flight, speculation and cyber risks that new cryptocurrencies could pose to China's financial system, and sought to leverage the advances made in (domestically developed) payment technologies (Chorzempa, 2021; Williams, 2021). In 2017, the PBOC established its Digital Currency Institute, which developed a first-generation CBDC prototype, and by the end of the year, Chinese commercial banks and payment institutions had joined the PBOC's CBDC development efforts. Those efforts were accelerated in 2019, upon Facebook's announcement of its intention to launch a global digital currency under the name of Libra, for fear of Chinese monetary sovereignty being eroded by a US firm (Chorzempa, 2021).

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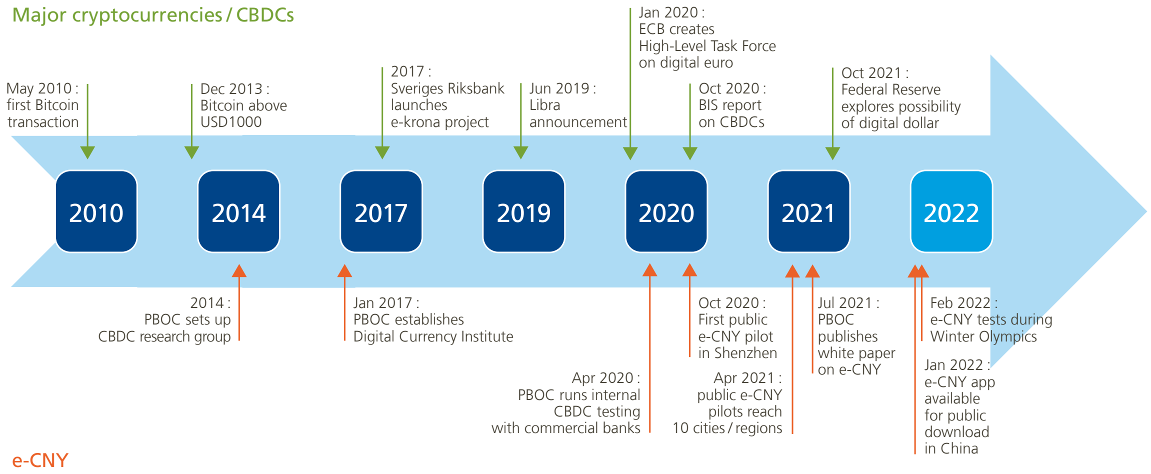
[1] For example, Ant Group's attempt to acquire MoneyGram International in 2018 was blocked by the US government's Committee on Foreign Investment over data security concerns.

[2] A CDBC can be broadly defined as a digital claim on a central bank that has currency/legal tender status. This sets it apart from other types of money, such as cash notes and coins (not digital), cryptocurrencies (digital but not a central bank liability nor legal tender), and central bank reserves (digital and a central bank liability but not legal tender) (Williams, 2021).

Chart 4

China makes steady progress on the e-CNY



Sources: Authors' own compilation based on Xiong and Feng (2021), PBOC (2021), and press reports.

After internal tests with commercial banks, October 2020 saw the first public e‑CNY pilot in Shenzhen, which was then soon expanded to several other major cities (Xiong and Feng, 2021). Typically, in such pilots Chinese residents register for a lottery and the winners receive e‑CNY in a digital test wallet on their smartphone – money that can be spent at selected retailers, on e‑commerce platforms, and / or to pay for transport, utility bills and government services, often within a certain time period (PBOC, 2021 ; Williams, 2021). Ever since testing began, millions of personal and corporate e‑CNY wallets have been opened and thousands of Chinese retailers have been involved, even though the e‑CNY's footprint in China's domestic digital payments remains tiny compared to overall digital payments (Kroeber, 2022). The February 2022 Winter Olympics in Beijing were supposed to be another key trial event, marking the first time that foreigners (both athletes and spectators) were given access to the e‑CNY, but limited attendance at the games – due to Covid‑19‑related restrictions – as well as safety warnings from Western governments, muted the e‑CNY's international debut. Meanwhile, the domestic roll‑out of the e‑CNY has continued. An e‑CNY app for iOS and Android was launched on Chinese app stores, available to all interested users (not just people selected through lotteries) in more than 20 cities across China that sign up through one of seven commercial banks or WeChat Pay and Alipay's online banks (Huld, 2022).

It was not until July 2021 that the PBOC released its first public white paper on the e‑CNY, providing further insights into the Chinese CBDC's characteristics, purposes and underlying motives. The PBOC (2021) stresses that the e‑CNY is perfectly equivalent to – and complements – the physical CNY, which will continue to be circulated as long as it remains in demand. As such, the e‑CNY is a "retail CBDC" issued to the general public, rather than a "wholesale CBDC" available to selected financial institutions for large settlements. Instead of being based on a decentralised network, as is the case with distributed ledger technology, the e‑CNY's architecture is two‑tiered and centrally managed : the PBOC is responsible for issuance and for selecting commercial and state‑owned banks as authorised operators, which in turn provide e‑CNY exchange services to the end users (consumers and businesses), often intermediated by other banks and payment service providers (Xiong and Feng, 2021 ; PBOC, 2021). In contrast to established BigTech platforms such as WeChat Pay and Alipay, that employ user data for the calculation of credit scores and the targeted marketing of loans, the e‑CNY promises to offer "managed anonymity". To sign up for the lowest‑level e‑CNY wallet, users just need to register their phone number, while access to larger digital wallets requires linking them directly to a bank account and real name.[1]

According to the PBOC (2021), the main objectives of the e‑CNY are threefold. A first goal is to satisfy the general public's demand for digital cash and support financial inclusion, since people without a bank account and / or nearby ATM would be able to access basic financial services via an e‑CNY wallet. The promotion of financial inclusion is an often‑cited motive for CBDC development, especially in emerging and developing economies (Boar and Wehrli, 2021). However, a key remaining question is whether the e‑CNY's features (such as its legal tender status and promises of enhanced privacy) and functionality (possibly including offline access) will draw many consumers and businesses away from the digital wallets of WeChat Pay and Alipay, which they have been using for years and that are tied in with many other services provided by Tencent and Alibaba (Chorzempa, 2021). This connects to the PBOC's second stated motive, which is to offer an "efficient and safe" alternative to existing retail payment services in China. It is not hard to read this motive as an attempt to regain more state control over the domestic payment system, in line with several other recent government interventions (see section 2.2). Third, while the e‑CNY's current design focuses squarely on domestic payments, the PBOC (2021) wants to actively explore the e‑CNY's potential for improving cross‑border payments.[2] Most experts are sceptical about the potential of the e‑CNY, by means

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[1] However, since in China all phone numbers are tied to an ID number, even small transactions will ultimately be traceable, although perhaps less easily so (Huld, 2022). In the end, the e‑CNY may not bring fundamental changes in terms of privacy. Already today, all non‑bank payments are cleared centrally and the PBOC can monitor them if it wishes. This will likely remain the case under the e‑CNY (Williams, 2021).

[2] In February 2021, the PBOC joined the Multiple CBDC (m‑CBDC) Bridge project initially set up by the BIS Innovation Hub, the Hong Kong Monetary Authority and the Bank of Thailand. The project, which is still at an early proof‑of‑concept stage, is developing prototypes of interoperable platforms that can execute (wholesale) cross‑border payments in digital currencies, as an alternative to the prevailing system of correspondent banking.

of its "first-mover advantage", to boost the Chinese renminbi's still very modest international role. Besides the many technical and legal difficulties associated with cross-border CBDC interoperability, the e-CNY's digital nature in itself does nothing to address the structural obstacles that have so far held back the adoption of the (physical) renminbi by foreign (central) banks and companies, notably the remaining capital controls in China and the renminbi's limited convertibility (Chorzempa, 2021). If the e-CNY's underlying payment system were rolled out further, it could in principle be used by China and allied countries to circumvent international payment sanctions by cutting out, say, US or European institutions and platforms (Williams, 2021). There are no indications of that happening so far in the context of the Western sanctions imposed on Russia for its invasion of Ukraine.

1.3 Case study: China's position in the semiconductor value chain

"Semiconductors" – a term used as shorthand to refer to the tiny chips composed of miniaturised electronic circuits layered on thin wafers of semiconductor material, typically silicon – are the essential components that power our smartphones, computers, telecommunication hardware, cars, industrial robots, military equipment and much more. Innovations in semiconductors also form the backbone to the transformative digital technologies of the future, including artificial intelligence, 5G/6G, autonomous electric vehicles, cloud/quantum/edge computing and the Internet of Things (Varas *et al.*, 2021). As the EC (2022a) puts it, there is no "digital" without semiconductors. Hence, it should come as no surprise that all major economic blocs, including the US, Europe, Japan and, of course, China, are paying close attention to the semiconductor industry – it has been the subject of many a policy plan and a focal point in the US-China technology conflict (see section 3). Interest in semiconductors has only further increased since the Covid-19 pandemic, when a combination of shifts in consumer demand, chip factory closures, a faster than expected economic recovery, geopolitical tensions and strategic stockpiling induced chip shortages that reverberated through various supply chains, particularly in the automotive sector (Bown, 2021; Kleinhans and Hess, 2021; EC, 2022a).

The global semiconductor value chain is extensive, highly complex and geographically dispersed. Depending on the specific type of semiconductor product, the manufacturing process may involve several hundred to more than a thousand steps, an ecosystem of several thousand suppliers, and up to 70 international border crossings (Varas *et al.*, 2021; US Department of Commerce, 2021). Throughout this complex value chain, several indispensable steps and inputs are controlled by just a handful of firms – or sometimes even a single one – due to far-reaching specialisation and high entry barriers in terms of knowhow and capital. Such a configuration creates a host of cross-country dependencies and "chokepoints" that countries with dominant market shares can exploit to isolate others (Lee and Kleinhans, 2021).

Chart 5 gives a very stylised, high-level overview of the various steps in semiconductor value chains. For each stage a number of key companies involved are listed, for illustrative purposes. In basic terms, the value chain is structured as follows.[1] Most innovations in semiconductors stem from fundamental research conducted in centres such as the Belgium-based Interuniversity Microelectronics Centre (IMEC), often sponsored by multinational consortia of universities and firms producing semiconductor inputs, designs or the actual chips (The Economist, 2021a). One can distinguish three important groups of inputs that go into the manufacturing process. First, various sorts of semiconductor manufacturing equipment (SME) are needed, where the biggest vendors include the US firm Applied Materials, the Dutch ASML and the Japanese Tokyo Electron. A second set of inputs consists of design software (so-called electronic design automation or EDA) dominated by firms such as Synopsis, Cadence and Siemens, and IP building blocks licensed by Arm and other firms. And third, manufacturing requires all kinds of specialised materials such as raw (silicon) wafers by firms like Shin-Etsu, Siltronic, and SK Siltron, and chemicals and gases supplied by major Japanese, European and American chemical companies, among many others. The software and IP are used to create chip designs which are then transplanted

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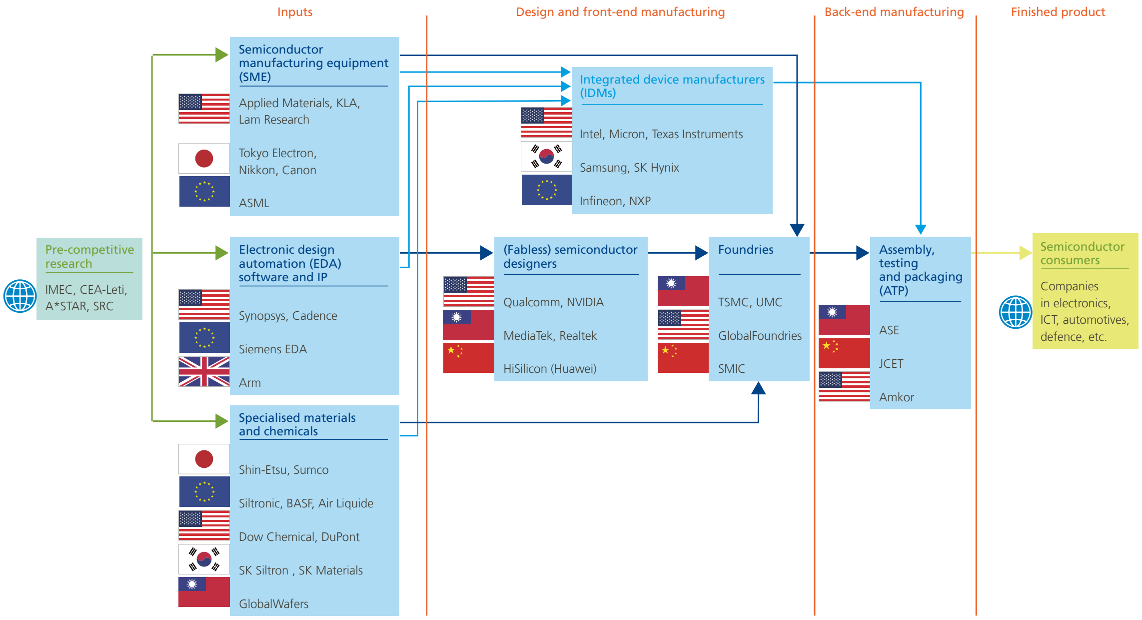
[1] See e.g., Bown (2020), Kleinhans and Baisakova (2020), Lee and Kleinhans (2021), and Varas *et al.* (2021) for much more detail.

Chart 5

Global semiconductor value chains are highly complex and geographically dispersed[1]



Sources: Authors' own elaboration based on Bown (2020), Kleinhans and Baisakova (2020), and Lee and Kleinhans (2021).

1 Value chain scheme is highly simplified and generalised. The companies mentioned are for illustrative purposes and represent only an unranked selection of key players. Flags refer to the location of company headquarters.

onto wafers in a fabrication plant using various types of SME and chemicals. This is done by either integrated device manufacturers (IDMs) that combine in-house chip design and manufacturing (such as Intel, Samsung and Infineon) or in a set-up where designated "fabless" chip designers (such as Qualcomm, NVIDIA, Mediatek and Huawei's subsidiary HiSilicon) collaborate with contract "foundries" (such as the Taiwan Semiconductor Manufacturing Company or TSMC – by far the largest player in this segment, GlobalFoundries and the Chinese Semiconductor Manufacturing International Corporation or SMIC).[1] After the "front-end" manufacturing process, the wafers are cut into individual pieces, tested and packaged in steps known as the "back-end", mostly performed by outsourced semiconductor assembly & test (OSAT) companies like ASE, Amkor and the Chinese Jiangsu Changjiang Electronics Technology or JCET.[2] Finally, the finished chips are sent to customers all over the world to be integrated in consumer electronics, ICT hardware, cars, etc.

Given China's role as the world's main manufacturing hub for electronic devices, it is also the biggest *consumer* of semiconductors, the large majority of which are imported, however.[3] To get a better view on the position of China and other countries in the just-outlined stages of semiconductor *production*, Chart 6 (left panel) provides an estimated breakdown of the industry's value added by production stage and country or region (excluding fundamental research). By and large, the US dominates in the activities that are most intensive in R&D, i.e. semiconductor design – which represents more than half of the gross profits generated in the industry – as well as design software and IP. US firms also occupy the leading position in the SME business, followed by Japanese firms. South Korea leads in the design of memory chips, such as the DRAM and NAND

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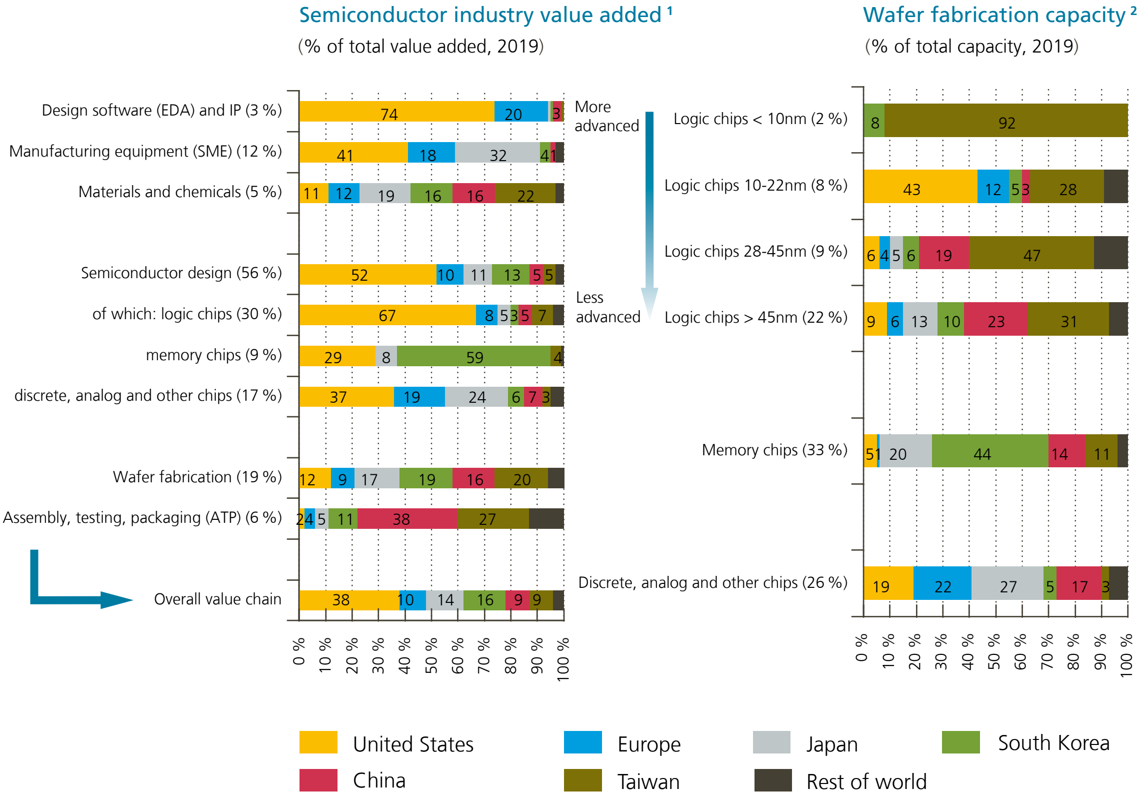
[1] Moreover, an increasing number of large end-users of semiconductors are designing their own (application-specific) chips, including companies such as Apple, Alibaba, Alphabet, Amazon, Facebook and Tesla (Kleinhans and Baisakova, 2020).

[2] OSAT companies also rely on specialised equipment and chemicals, but to a lesser extent than front-end fabs. Some IDMs or foundries do the assembly, testing and packaging in-house.

[3] As Garcia-Herrero (2021) points out, Chinese imports of semiconductors have exceeded the country's oil imports since 2015.

Chart 6

China is a key player only in chip assembly, testing and packaging, and in trailing-edge chip fabrication



Sources: Varas *et al.* (2021).

1 Shares on the left-hand side (in brackets) are based on gross profits. Country/regional breakdowns are based on company revenues and location of headquarters, except for wafer fabrication and assembly, testing, packaging, where they are based on installed capacity and location of the facilities.

2 Country/regional breakdowns are based on location of the facilities.

chips for data storage found in computers and flash drives. Europe is dominant in none of the broadly defined activity classes but is home to key players in fundamental research (with institutes such as IMEC, CEA-Leti and Fraunhofer-IAF), in particular SME (most notably the extreme ultraviolet lithography machines in which ASML has a monopoly), and in certain niches, like chip design/manufacturing for automotive and industrial electronics (with European IDMs Infineon, NXP, STMicroelectronics and Bosch). The supply of specialised materials and most of the actual manufacturing, which are relatively capital-intensive activities, are concentrated in Asia. As Chart 6 (right panel) shows, in 2019 more than 90 % of the capacity to produce the "leading-edge" logic chips (used for processors), with the smallest nodes, is found in Taiwan, with the remainder located in South Korea.[1] The latter is also home to the largest manufacturing capacity for memory chips. Fair shares of logic, memory and other chips are produced in China, but only of the more mature,

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[1] Semiconductor innovations, especially in logic and memory chips, are often expressed in terms of "nodes", originally the size in nanometres of the transistor gate in electronic circuits but now an umbrella concept to designate the size of chip features, different architectures and manufacturing technologies used. Generally, the smaller the "node size", the more components per area a chip can pack and thus the more powerful it is (but also the more complex and expensive it is to produce) (Varas *et al.*, 2021). At the time of writing, the most advanced logic chips in commercial production (by TSMC and Samsung) were of the 5 nanometre (nm) node size, with 3 nm in pre-production and 2 nm under development (EC, 2022a).

“trailing-edge” kind, and mostly by foreign firms (accounting for two-thirds of China-based production), rather than domestic ones (such as SMIC and Hua Hong). One area in which China (i.e., both Chinese firms like JCET and foreign firms with facilities in China) is a key player is the back-end assembly, testing and packaging (ATP) of chips, which is more labour- and less capital-intensive than front-end manufacturing and represents only a limited share of the total value added in the semiconductor chain.

All in all, China currently occupies only a modest role in the semiconductor value chain, perhaps not unsurprisingly so, given that it is a latecomer to an industry with many already firmly established companies, high entry barriers and strong learning-by-doing effects. Like others, and especially for frontier chips and advanced semiconductor inputs (equipment and software), the country is still heavily dependent on foreign (often US) suppliers, which makes it vulnerable to export controls and other sanctions (see section 3.1). To reduce China’s reliance on semiconductor imports and to support the development of chip-heavy sectors and digital technologies in which it aims for global leadership (including artificial intelligence, electric vehicles as well as military applications), Chinese authorities have staged several industry-specific policy plans and interventions over the years.

While the targeting of semiconductors in Chinese policy goes back several decades (to the 1950s), the launch of the State Council’s National Integrated Circuit Industry Development Outline in 2014 tends to be seen as a watershed event in China’s policy approach to semiconductors (VerWey, 2019a; He, 2021; SIA, 2021). The 2014 Outline listed targets for upgrading in all main segments of the semiconductor value chain, from chip design to ATP, to be supported by ample state-linked funding and policies seeking to accelerate technology transfer. Most notably, the 2014 Outline established the National Integrated Circuit Industry Fund, also known as the “Big Fund”, which raised about RMB 140 billion (more than USD 20 billion) in capital over 2014-2019, mostly from the Chinese Ministry of Finance and the state-owned China Development Bank (Lee and Kleinhans, 2021). The Big Fund attracted multiples of this “seed capital” to the Chinese semiconductor sector from other sources, including provincial governments and private (tech) firms. 2019 saw the start of the second phase of the Big Fund, with registered capital of roughly RMB 200 billion (more than USD 30 billion). The broader “Made in China 2025” plan (see section 2.1) issued in 2015 also paid special attention to semiconductors, introducing the highly ambitious target of producing 40 % of the semiconductors China uses domestically by 2020, and of achieving 70 % self-sufficiency by 2025. Together these strategies appear to promote a “fast-follower” approach, recognising the structural barriers to reaching the global technological frontier – and thus the need to remain engaged with the industry’s leaders –, while at the same time trying to accelerate technological catch-up and to gradually reach higher value-added positions in the semiconductor chain, where possible through leapfrogging by means of domestic innovations (VerWey, 2019a; Lee and Kleinhans, 2021).

China’s semiconductor plans have been supported by public R&D funding, direct subsidies, below-market financing, favourable tax and IP regimes, as well as the active promotion of inbound and outbound FDI. A firm-level study by the OECD (2019) concludes that, over 2014-2018, the resulting government support for key Chinese semiconductor companies (SMIC, Hua Hong, JCET and Tsinghua Unigroup) was significantly larger, relative to firm revenues, than in other jurisdictions, with a particularly important role for below-market equity financing (reflecting large investments by the Big Fund and other central and local government funds). The study also finds a direct relation between state-linked equity injections and the construction of new semiconductor fabs in China. In addition, both the OECD (2019) and VerWey (2019a) show a remarkable increase in Chinese outward M&A activity in semiconductors following the creation of the Big Fund, mostly involving (smaller) US and European firms. Since 2018, however, Chinese overseas acquisitions in the sector have noticeably slowed down due to a tightening of Chinese restrictions on capital outflows and – probably to a greater extent – by increasingly stringent foreign investment screening by the US and others for strategic and/or national security reasons (see Buysse and Essers, 2019; Duchâtel, 2021). Similarly, international R&D cooperation has benefited China in terms of technology transfer but has become much more sensitive in the wake of the technology tensions with the US (see section 3.1).[1]

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[1] For example, SMIC’s 14 nm “fin field-effect transistor” process was developed through a joint R&D technology venture together with Huawei, Qualcomm and IMEC, starting in 2015 (Duchâtel, 2021). In a September 2021 interview with The Economist (2021a), IMEC’s CEO describes the centre as the “Switzerland of semiconductors” but adds that it has no “major partnerships” with up-and-coming Chinese toolmakers.

With the intensification of US export controls and other sanctions hitting Chinese semiconductor companies, there has been an even stronger push by the government and those companies themselves to look for alternative sources of inputs, ideally produced domestically. This search has been informed by extensive and extremely detailed supply chain audits, in which companies' first-, second- and n-tier suppliers are reviewed and scored for geopolitical risk (Ting-Fang and Li, 2021). The reinvigorated strive for self-reliance has also led to an unprecedented surge in local chip champions and new start-ups looking to position themselves in the Chinese semiconductor ecosystem. But while all US (or other) market leaders in the semiconductor industry now have Chinese "Doppelgängers", the latter are often still a long way from offering a viable alternative to – let alone competing with – the former.

Despite impressive policy efforts and substantial resources allocated to the development of the Chinese semiconductor industry, the results on the ground have been mixed, at best, and vary along the value chain (see Lee and Kleinhans, 2021; Kleinhans and Lee, 2021; Duchâtel, 2021; SIA, 2021). As mentioned before (see Chart 5), the ATP segment is where some of China's greatest successes have been booked, with a fast-growing market share for Chinese firms, even though the high-end packaging subsegment remains dominated by foreign firms (including TSMC and ASE). With respect to front-end manufacturing, in 2020 China-located fabrication accounted for less than 16 % of Chinese domestic chip consumption, and was expected to stay below 20 % in 2025, a far cry from the goals set out by Made in China 2025 (IC Insights, 2021). While China's share in wafer fabrication is poised to further increase, experts judge it to be nearly impossible for China to compete with cutting-edge foundries within the next ten years (Lee and Kleinhans, 2021). In the SME segment, Chinese firms have some presence in the many different SME subcategories, but the Chinese SME sector has only a miniscule market share overall and remains years away from the technological frontier, notably in advanced lithography. Software (EDA) and IP are other segments where the outlook for China's upgrading seems rather bleak. China's leading EDA firm, Huada Empyrean, plays only a limited role, even on the domestic market. VeriSilicon is the only significant (top-10) Chinese IP provider, backed and used by leading IDMs and digital companies, whereas the joint venture Arm China has been mostly a sales unit for the globally dominant IP licences developed by its UK parent company. Perhaps the upcoming open-source processor architecture RISC-V, in which China has started to invest, may provide opportunities for leapfrogging. In the area of chemicals and materials (including raw wafers), there has been some progress in creating capacity for import substitution, albeit not yet for material types with the strictest purity requirements. Moreover, China has the advantage of dominating the extraction and processing of several rare earth minerals used by the semiconductor industry. Finally, thanks to the fast-expanding domestic market for digital applications and the ample policy attention received, China's chip design sector has grown rapidly. Alongside the entry of large established platform companies such as Baidu, Alibaba and Tencent into chip design, the sector has seen the emergence and growth of many new firms, a few of which now approach the global technology frontier (e.g., Huawei's HiSilicon, Goodix and OmniVision), even though their share of worldwide revenues remains small. Altogether, given these pockets of excellence and a dynamic start-up scene, chip design is considered the value chain segment where Chinese firms may stand the best chance of competing at the frontier over the next decade.

More generally, considered over the whole value chain, the main obstacles that currently hamper and (for the foreseeable future) will continue to hamper the development and rise to stardom of China's semiconductor industry are believed to be threefold (Duchâtel, 2021). First of all, geopolitical tensions and the associated restrictions on access to US and other foreign technology threaten the business continuity and progress of Chinese semiconductor firms (see section 3.1). Chinese policymakers have little traction on this major obstacle. Second, despite rapidly growing numbers of graduates in ICT programmes, China is confronted with a shortage of highly specialised human resources with sufficient practical experience. In the past, due to a dearth of domestically trained-on-the-job talent, Chinese firms have relied intensively on the "poaching" of Taiwanese, Japanese and Korean engineers and executives from leading foreign companies, lured away by higher salaries and other benefits (VerWey, 2019b; Lee and Kleinhans, 2021). Third, China's top-down, state-led innovation-driven approach has resulted in a lot of wasted or misallocated funds, often geared towards short-term and highly visible projects. Arguably, insufficient attention has been paid to creating links between R&D and market demand and positive synergies within the Chinese semiconductor ecosystem (Duchâtel, 2021; He, 2021).

2. China's digital policy stance

The previous case study on semiconductors illustrates the scale on which industrial policies are used in China to steer the development of a sector in line with objectives set by the state. Such an approach is replicated in all other sectors that are considered "strategically important", as part of a larger masterplan. The section below describes this philosophy in a more general way and highlights the orientations found in China's most recent Five-Year Plan. The next section gives an overview of China's tech crackdown in 2021, which sharply raised the influence of the Chinese government over the digital economy, and argues that it can be seen, at least partly, as a correction of an anomalous situation.

2.1 Ambitious innovation-driven industrial policies

The publication of "Made in China (MIC) 2025" in 2015 launched a new approach to industrial policy in China, characterised by its comprehensiveness, generous funding and strong political backing at the highest level (Buysse and Essers, 2019). MIC 2025 was subsequently integrated with other policy documents, such as the Internet Plan, into an overarching vision of technological change: China's "Innovation-driven development strategy" (IDDS) approved by the State Council in May 2016. The underlying idea is that the unfolding technological revolution provides China with a once-in-a-lifetime opportunity to move directly to the technological frontier and to leapfrog other economies. In addition, the government recognised that the broad applicability of the new technologies would also transform traditional industries. This created a sense of urgency and resulted in a sophisticated techno-industrial masterplan, targeting both broad technological change and specific industrial sectors using a range of instruments.

The new approach to industrial policy reflects a genuine belief on behalf of policymakers that they can create a system that merges the efficiency of the market with the ability of the government to steer the economy (Naughton, 2021). In this approach, the government takes on the role of the "investor state" or "CCP Inc" (Grünberg and Wessling, 2021). In fact, the most important new instrument at the core of the strategy is the "Industrial Guidance Fund" (IGF), an investment fund primarily sponsored by state-owned enterprises and/or central or local government agencies and managed by professionals operating under clear incentive contracts. The objective is to guide capital and other resources towards key areas of strategic importance. As of the first quarter of 2020, Chinese officials had set up 1741 IGFs (Luong *et al.*, 2021). Naughton (2021) estimates that by mid-2020, IGFs had reached a total designated funding scope[1] of RMB 11.27 trillion (roughly 11 % of China's 2020 GDP) and notes that such commitments represent the greatest single commitment of government resources to an industrial policy objective in history.

The 14th Five-Year Plan (FYP) adopted in March 2021, covering the period 2021- 2025, is mostly a continuation of the IDDS, seeking to promote high-tech manufacturing and indigenous innovation. The plan commits the government to massive subsidies for commercial technology applications, investments in new technology infrastructure, and increased funding in "hard" tech sectors such as semiconductors, telecommunications, artificial intelligence, quantum information, and new materials. The 14th FYP aims to increase total R&D spending by more than 7 % over the five-year period covered by the plan, to raise the share of fundamental research in total R&D spending from the current 6.2 % to at least 8 % in 2025, and to double the number of high-quality invention patents by 2025 (Evans-Pritchard and Williams, 2021).

Compared to the previous FYPs, the call for greater technological self-sufficiency has become much stronger. The trade and technology war with the US (see section 3.1), and more generally the perception of a more

[1] The value of RMB 11 trillion is a stock rather than a flow. The figure is significantly larger than the cumulative flow of investment into projects. In the first place, not all the IGFs have raised all of the money specified in the agreements. According to Luong *et al.* (2021), the IGFs had raised a total of almost RMB 5 trillion. Furthermore, after money is raised, it takes time to appraise investments and begin to spend the money.

hostile international environment, has raised policymakers' concerns about China's technological dependence on advanced economies. Such dependence makes China vulnerable to disruptions caused by (US) sanctions whose sole purpose, at least in the eyes of Chinese leaders, is to inflict economic damage and hold back the country's development. From an economic and national security viewpoint, it is therefore deemed necessary that critical links in industrial supply chains become vertically integrated within China (Segal, 2021). This is a daunting challenge in the short run as the barriers to self‑reliance are still high, especially in the semiconductor sector (see section 1.3). But in the longer run, the Chinese economy and innovation system will most likely become more self‑reliant and inward‑looking.

The ambition to make the Chinese economy more innovative and resilient and less vulnerable to foreign (above all US) pressures reveals itself in a new concept known as "dual circulation strategy", which occupies a central place in the 14th FYP. The concept refers to the dual objective of strengthening the domestic market (domestic circulation) while deepening China's integration in the world economy (international circulation). Rising consumption and indigenous innovation are the main drivers of the domestic circulation, yet the underlying notion is to ensure that increased demand is met by domestic production rather than imports (Garcia‑Herrero, 2021). The implication is that imports of essential external inputs should increasingly be replaced by domestic production as soon as domestic equivalents become available (Segal, 2021). At the same time, China remains committed to its integration in the world economy and, according to the 14th FYP, aims to improve its trade regime by removing some barriers and to promote the imports of high‑quality goods, advanced technology, and energy products from geographically more diversified sources. The ultimate objective behind this openness, nevertheless, remains the upgrading of Chinese exports and their expansion to new markets (Pei, 2021).

The push for indigenous innovation does not mean that China is turning its back on foreign direct investment (FDI). The policy thrust regarding FDI is still towards further liberalisation, albeit on China's terms (Brown *et al.*, 2021). There is a wide range of non‑sensitive domestic industries where China is eager to expand market access and encourage FDI to benefit local growth and development. In areas of critical technology where China is still lagging behind, policymakers are rolling out the red carpet to facilitate the onshoring of critical inputs by foreign companies. More generally, foreign companies in sensitive industries wanting to do business in China are faced with a difficult trade‑off between localising supply chains, data and research, or missing out on the Chinese market. This may prompt some of them to leave China over time.

2.2 Shift from enabler to heavy‑handed regulator

For all the focus of the Chinese government on industrial policy, one contributing factor to the rise of China's BigTech giants has been the light regulatory environment in which they have operated. China's hands‑off approach towards BigTech shifted suddenly with the suspension of Ant Group's USD 37 billion initial public offering (IPO) in November 2020. Initially viewed as a retaliation against its founder Jack Ma for a critical speech given one month earlier, the IPO suspension turned out to be the start of a genuine regulatory crackdown on technology companies. Numerous other regulatory actions followed in 2021 against dozens of Chinese firms (e.g., Tencent, Didi Chuxing, Meituan) for various alleged offences, including anti‑competitive practices such as signing exclusive contracts, failure to disclose acquisitions, misleading marketing tactics, poor social protection and low remuneration of delivery workers, data security breaches, and the use of offshore holding companies to circumvent limits on foreign ownership. Concerned about financial stability and BigTech finance having become "too big to fail", financial regulators required that BigTech firms separated their financial products/lending services from their other business activities including payment platforms. In addition, Ant Financial had to place its credit scoring entity in a separate joint venture with a local state‑owned group, and Ant Group had to be restructured as a holding company overseen by the PBOC.

Table 1

Government / Party control over the digital economy intensified in 2021

Common prosperity / Anti-trust	Financial stability	Privacy and national security
Platform companies	**FinTech and BigTech finance**	**Use and storage of data**
Ban on offshore constructions (2021)	Crackdown on P2P platforms (2016-2020)	Cybersecurity Law (2017)
Guidelines to protect delivery workers (2021)	Cancellation Ant Group's IPO (2020)	Personal Information Protection Law (2021)
Ban on for-profit tutoring platforms (2021)	Ant's Alipay break-up (2021)	Data Security Law (2021)
Anti-Monopoly Guidelines on the Platform Economy (2021)	Ban on cryptocurrencies (2021)	Regulation of internet recommendation algorithms (2022)

Source: Authors' own compilation based on press reports.

Efforts to control data and internet content are not new. China has long been known for its "Great Firewall" blocking access to sensitive information on the internet. Its Cybersecurity Law came into effect in 2017 and included provisions on data localisation and requirements for network and system security in line with international norms. Yet, the enactment of three noteworthy laws covering the use of data in recent months signals a more ambitious plan by the Cybersecurity Administration of China to establish a Chinese model of digital governance (Tan, 2022). The Personal Information Protection Law regulates the protection of individual data and imposes consent requirements on companies handling such data. The Data Security Law sets up a framework for the classification of data based on their potential impact on China's national security and regulates its protection depending on the data's classification level. "Core data" – broadly defined by the law as any data that concerns Chinese national and economic security, citizens' welfare and/or significant public interests – receive the highest level of protection. Both laws add new restrictions on cross-border data flows and tighten data localisation requirements, to a point where all data generated in China must stay in the country, unless the relevant authorities grant explicit permission to transfer some of it overseas. Moreover, China has been the first to introduce regulation governing the use of recommendation algorithms by technology companies (Tan and von Canap, 2021).

The immediate impact of this regulatory shift has been a sharp decline in the valuation of some of China's largest and best-known tech companies, leading to a sudden drop-off in the stock market indices tracking Chinese tech stocks. The new laws on data security effectively discourage domestic technology firms from listing abroad by the requirement to clear a security review prior to any international IPO. Likewise, foreign technology firms wanting to invest in areas defined as critical information infrastructure – this covers any network equipment, service providers and data management systems – are subjected to a national security review (Brown *et al.*, 2021). However, there are no signs that the private sector at large is being crushed. In fact, the Chinese BigTech companies subjected to this campaign are only a relatively small component of a large private sector that is still investing, growing, and outperforming the state sector (Huang and Lardy, 2021). Moreover, a review of company-registration data by The Economist (2022) shows that firms dealing in big data, artificial intelligence, the Internet of Things, robotics, cloud computing and clean energy are setting up at an unprecedented pace in China's interior.

Many of the interventions were long overdue. For over a decade, China's digital pioneers flourished in a regulatory vacuum reminiscent of the "Wild West" (Zhu, 2021), to a point where a few digital platforms became dominant and started to abuse their market power. The regulatory crackdown can therefore be seen as an attempt by China's Communist Party to regain control over the strategically important technology sector and to ensure that its behaviour is aligned with Party priorities (Grünberg and Wessling, 2021). Key objectives of the Party are to safeguard financial stability, crack down on anti-competitive behaviour and corruption, boost social fairness, and ensure privacy protection (IMF, 2022). Many of these concerns are broadly shared by the US government and the EU, among others.

Another possible motivation which is very specific to China is the government’s ambition to guide the orderly allocation of capital and redesign the industry according to its blueprint (Naughton, 2021). The digitalisation of society is of such a strategic importance that, in the view of the Chinese authorities, it cannot be left to market forces alone. Therefore, the Chinese government believes it must intervene to reshape the Chinese tech industry according to its own vision (The Economist, 2021b), prioritising the development of “hard” technology (cloud computing, artificial intelligence, self-driving cars, semiconductors) over “soft” technology (social media, entertainment, e-commerce). Since the Chinese authorities now consider the tech sector as the strategic high-ground in Sino-US competition (Tan, 2022), the sector has become the central focus of China’s new industrial policy (see section 2.1).

3. US and EU taking on digital China

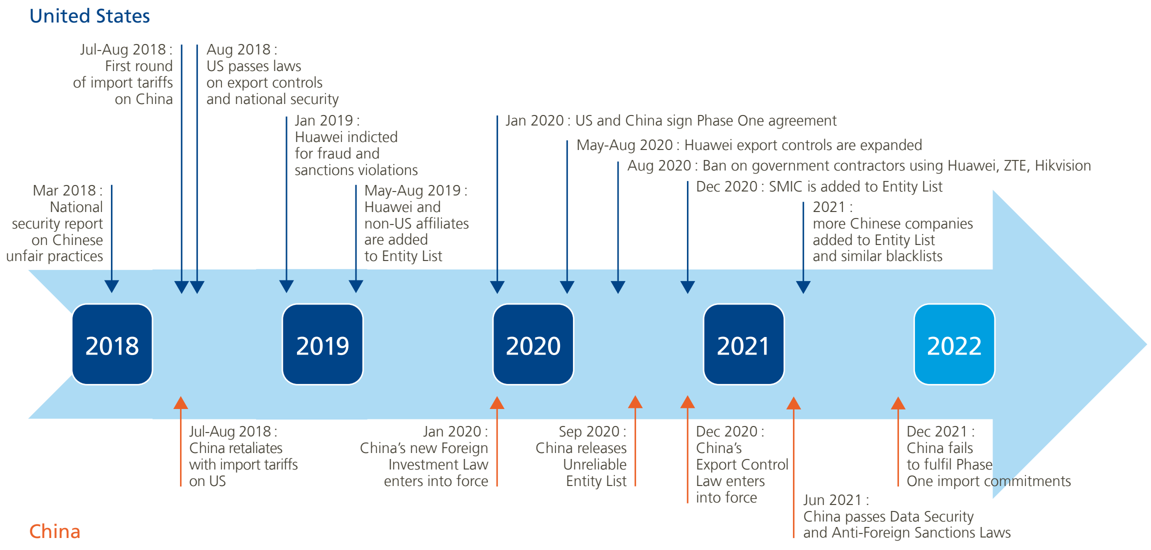
3.1 US-China technology conflict

Technological rivalry between the US and China has a long history. However, tensions have significantly increased since the Trump presidency, with few signs of abating under the Biden administration (Cordemans *et al.*, 2018 ; Bown and Kolb, 2022). Chart 7 shows a timeline of the key US government policy actions taken against alleged misconduct by “digital China” as well as some Chinese retaliatory measures.

In March 2018, the US Trade Representative published a report on China’s unfair trade and investment practices, articulating in great detail a myriad of long-standing complaints, among other, allegations about discriminatory subsidies and other government support, forced technology transfer, insufficient IP protection, and industrial espionage and cyber theft. Problematic Chinese practices with respect to digital technologies and semiconductors received ample attention in the report (USTR, 2018a ; 2018b). In July-August 2018, backed by the report’s findings, the Trump administration launched a first round of 25 % tariffs on USD 50 billion worth of goods imported from China, focusing on products that contributed to or benefited from the Made in China 2025 strategy, including computer and electronic devices, robotics, industrial equipment and semiconductors.

Chart 7

US-China technology tensions have built over time and show no clear sign of abating



Sources : Authors’ own compilation based on Bown and Kolb (2022), Drinhausen and Legarda (2021), and press reports.

As most of the targeted goods are embedded in global value chains, the collateral damage of such tariffs on US and US-allied firms was deemed to be substantial (Lovely and Liang, 2018). China was quick to retaliate with its own tariffs on imports from the US, mostly targeting agricultural goods and food. Notably, the retaliatory tariff list excluded most US semiconductors and related manufacturing equipment, as these remain necessary inputs for the Chinese electronics industry and China's own semiconductor fabs (Bown, 2020).

Over the course of 2018 and 2019, the US and China engaged in a fully fledged trade war, with multiple rounds of escalating tariffs on each other's imports; by the end of 2019, no less than 66 % of total Chinese exports to the US and 58 % of US exports to China were subject to punitive tariffs (Bown and Kolb, 2022). Only in January 2020 did the US and China agree on a temporary truce by signing the so-called Phase One agreement. This agreement left the newly imposed bilateral tariffs in place but made China commit to buy an additional USD 200 billion worth of US exports, relative to the 2017 baseline, up to the end of 2021. China also pledged to make progress on IP protection and market-based technology transfer. Ultimately, China bought less than 60 % of the total imports it had committed to, not even enough to attain pre-trade-war import levels. Interestingly, however, China's purchases of US semiconductors and SME *did* significantly accelerate over 2020-2021, due to stockpiling by firms hit by US export controls such as Huawei and SMIC (see below) as well as the pandemic-induced booming demand for (China-produced) consumer electronics (Bown, 2022). While the Biden administration did not annul the Phase One agreement with China, in March 2022 it did exclude some 350 specific products from the Section 301 tariffs imposed by the Trump administration, in order to provide selective relief to US importers (Bown and Kolb, 2022).

Meanwhile, in August 2018 the US had also passed a new defence law containing two key provisions, the Foreign Investment Risk Review Modernization Act (FIRRMA) and the Export Control Reform Act (ECRA), aimed at expanding the mandate and resources of the Committee on Foreign Investment in the United States (CFIUS) and updating export controls on "emerging and foundational technologies". Even though the provisions did not explicitly single out China, they originated from bipartisan concerns about Made in China 2025 and the risks posed by Chinese state-linked investments in the US (Chorzempa, 2018b).

In January 2019, the US Department of Justice indicted Chinese telecom giant Huawei, including for financial fraud and violations of US sanctions (against Iran). Together with national security concerns about the company's 5G network equipment, this led in May 2019 to the US Department of Commerce adding Huawei to its so-called Entity List, the official inventory of foreign companies for which it is illegal for US companies to supply goods or services without a government-approved licence. In August 2019, dozens of Huawei-affiliated companies, including Europe-based subsidiaries, were also put on the Entity list (Buysse and Essers, 2019). This implied that Huawei was effectively cut off from US-made semiconductors (produced by, e.g., Intel or GlobalFoundries), and Huawei's chip design arm HiSilicon could not access US-made software (by, e.g., Synopsys or Cadence) – an attempt to obstruct Huawei's production of 5G equipment (Bown, 2020). However, these initial export controls did not prevent Huawei from purchasing the chips it needed for its 5G base stations from Taiwan (TSMC) and South Korea (Samsung). Hence, the US further expanded its export controls on Huawei in May and August 2020 by also taking into consideration US-made inputs used in other parts of the semiconductor supply chain: without an export licence, foreign chip manufacturers like TSMC and Samsung would no longer be allowed to supply (sophisticated) chips to Huawei if those chips were designed/fabricated using US software or equipment (by, e.g., Applied Materials, Lam Research or KLA) (Bown, 2020; Duchâtel, 2021). As a result, due to the US "weaponising" its dominant position in the upstream part of the value chain, Huawei and its affiliates also became increasingly isolated from *non-US* foreign chips and chip inputs. In December 2020, the major Chinese foundry SMIC was added to the US Entity List.[1] Over the course of 2021, the Biden administration further amended the Entity List (and similar blacklists for the purpose of US exports and investments), adding several other Chinese digital

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[1] The US has also applied indirect pressure on SMIC through the Wassenaar Arrangement, a multilateral regime of export controls on conventional weapons and dual-use goods and services established in 1996. Back in 2019, the US government is said to have lobbied its Dutch counterpart, with success, to deny Dutch firm ASML an export licence for the sale of one of its extreme ultraviolet lithography machines to SMIC (Duchâtel, 2021).

technology companies – for their alleged links to and / or support to the Chinese military –, including (smaller) semiconductor firms and producers of quantum computers and surveillance technologies (drones, facial recognition, etc.).[1]

Growing export controls and other restrictions have led to shifts in the targeted Chinese tech firms' supply chains and / or business models[2] and have given further impetus to the Chinese government's plans of reducing dependence on US suppliers and technologies, most notably in the semiconductor industry (Ting-Fang and Li, 2021 ; see section 1.3). China has also responded by upgrading its arsenal of potential countermeasures, including a new Foreign Investment Law (in force since January 2020), an Unreliable Entity List (released in September 2020), an Export Control Law (in force since December 2020), a Data Security Law, and an Anti-Foreign Sanctions Law (both passed in June 2021). All of these laws grant the Chinese government (typically broadly defined) powers in imposing their own trade and investment restrictions on foreign companies, as well as in taking retaliatory actions against the restrictions enacted by others (Drinhausen and Legarda, 2021). So far, however, in its semiconductor conflict with the US, China has chosen not to resort to the provisions under such laws nor to use its levers in the chips value chain (e.g., in testing and packaging, rare earths, or its large chip consumer market). Escalating the conflict would likely further reduce the foreign investment and foreign technology that China's emerging semiconductor ecosystem still so badly needs (Daly and Schneider, 2021).

As with the tariff war, the US tech industry itself has not been left unscathed by the semiconductor export controls, since they have implied lower sales revenues to China and the prospect of other foreign buyers switching to alternative, non-US suppliers (Bown, 2020). The US Semiconductor Industry Association (SIA) has spoken out against a wholesale decoupling of the US and Chinese semiconductor sectors and has instead called for US collaboration with its allies on new global rules and standards (including by the WTO) and, where needed, multilateral, more narrowly defined export controls (SIA, 2021). SIA has also actively lobbied for the "Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America" Act, which would establish investments and incentives to support semiconductor R&D and manufacturing in the US as well as supply chain security. In June 2021 and February 2022 respectively, the US Senate and US House of Representatives passed broader competitiveness legislation providing for USD 52 billion in federal government funding for the CHIPS Act, but a compromise on the exact form and target of the support was still being sought at the time of writing. US Congress is also contemplating an SIA-endorsed "Facilitating American-Built Semiconductors" (FABS) Act, which focuses specifically on tax credits for investments in semiconductor manufacturing and design (SIA, 2022).

3.2 EU digital policies and steps toward transatlantic cooperation

While EU policymakers have typically been less vocal than their US counterparts in criticising China on unfair trade, investment and technology practices, and have steered clear from ratcheting up an all-out technology conflict, they do share many of the US concerns about China (Buysse and Essers, 2019).[3] In recent years, the EU has therefore expanded its toolbox to deal with an increasingly assertive (digital) China. In April 2019, the EU's common framework for FDI screening entered into force, creating a platform for monitoring and exchanging information on incoming FDI with a potential impact on critical inputs, infrastructure and technologies, including in artificial intelligence, robotics, semiconductors and cybersecurity. Individual EU member states, however,

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[1] Some surveillance technology companies, most notably Hikvision, had already been blacklisted under the Trump administration. Moreover, starting in August 2020, the US government is banned from working with contractors that use products from Huawei, Hikvision or ZTE.

[2] For example, Huawei has turned away from its previous core business of developing and selling telecom network gear and smartphones, areas where the company's revenues have plummeted due to the loss of access to advanced semiconductors and related inputs. Instead, Huawei is reported to have invested heavily in chip packaging and in R&D in emerging technologies such as 6G, cloud services and autonomous vehicles (Hille *et al.*, 2021).

[3] At the latest EU-China Summit of April 2022, "[t]he EU raised the importance of a transparent and competitive environment for the digital economy, as well as trustworthy and ethical uses of artificial intelligence. It expressed concerns about increased cybersecurity threats and called for responsible state behaviour in cyberspace" (European Council, 2022). The EU and China also committed to resume their bilateral High-Level Digital Dialogue, an event (organised for the first time in September 2020) during which issues such as ICT standards, product safety, artificial intelligence, digital taxation, research and innovation are discussed.

retain the power to decide whether or not to block a particular investment. The European Commission has also proposed new regulations (still to be further negotiated with the European Parliament) to address distortions to the Single Market caused by foreign subsidies, which would give it the power to investigate financial contributions granted by non-EU governments to companies making acquisitions or participating in public procurement in the EU, and to take remedial actions (EC, 2021a). While China is not explicitly mentioned, such instruments and rules seem to be mostly inspired by concerns about state-owned or -sponsored Chinese firms (often tech companies themselves and/or targeting EU tech companies). Somewhat in contrast with these initiatives, in December 2020 the EU and China had reached an agreement in principle on bilateral investment, after more than seven years of negotiating. With the so-called EU-China Comprehensive Agreement on Investment (CAI), EU policymakers hoped to achieve greater reciprocity in market access, including a gradual opening of China's IT services and cloud computing sector, stricter controls on forced technology transfer and on discrimination between Chinese SOEs and EU companies, and greater transparency on state subsidies. However, in May 2021 the European Parliament froze the CAI ratification process in response to Chinese sanctions on several European organisations and political representatives – a retaliation for EU sanctions in relation to human rights violations in China's Xinjiang region (Codogno, 2021). CAI discussions have not reopened since.

In the meantime, Chinese and US policy plans also appear to have induced the EU to step up its own ambitions in the area of digital technologies. This is evident from the Commission's New Industrial Strategy for Europe agenda, launched in March 2020 and updated in May 2021 (EC, 2020b; 2021b). This broad agenda seeks to accelerate the twin green and digital transitions, while at the same time strengthening Europe's "(open) strategic autonomy", generally understood as its capacity to act autonomously when and where necessary and with partners wherever possible. The industrial strategy calls for a better integration of the national digital and electronics sectors at the European level and for Europe's strategic dependencies to be identified and reduced. In May 2021, a first mapping exercise, similar to what has been done by US authorities, looked at dependencies in the areas of semiconductors (highlighting strong reliance on the US for chip design tools and on Asia for advanced chip fabrication; see section 1.3) and cloud/edge computing (highlighting the dominant positions of Amazon, Microsoft, Google and Alibaba) (EC, 2021c). A second mapping round in February 2022 also considered dependencies in the cybersecurity sector (highlighting that the majority of cybersecurity hardware and software is developed in the US and manufactured in China) (EC, 2022b). Arguing that market failures sometimes prevent the funding of large-scale (cross-border) innovative projects that would be needed to reduce such strategic dependencies on the US and China, the Commission has set up various so-called Important Projects of Common European Interest (IPCEIs). Supported by relaxed state aid rules, these IPCEIs aim to mobilise both private and public investment, and to bring together companies from different subsectors and countries to increase European-level coordination. With respect to digital technologies, there has been one IPCEI on microelectronics since 2018, and two more IPCEIs, on semiconductors and cloud computing, were being established at the time of writing.[1] While IPCEIs may potentially accelerate innovative breakthroughs and thereby enhance strategic autonomy, without strong safeguards they also risk benefiting mostly large established companies and distorting intra-EU competition (Poitiers and Weil, 2022).

The EU has also drawn up dedicated digital policies. In its Digital Compass of March 2021, the Commission explicitly spelled out its digital ambitions for 2030, to be monitored by means of quantitative targets, such as the goals to employ 20 million ICT specialists in the EU; to provide 5G coverage for the entire EU; and to produce at least 20 % of the world's cutting-edge and energy-efficient semiconductors in the EU (EC, 2021d).[2] To help finance these and other digital ambitions the EU's 2021-2027 Multi-annual Financial Framework (MFF) includes a Digital Europe Programme with a budget of about EUR 7.6 billion for strategic investments in digital projects. This is to be considered complementary to several other national and EU-level funds (within or outside of the MFF), including Horizon Europe, Connecting Europe, the Recovery and Resilience Facility, InvestEU and the

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[1] Moreover, in July 2021 the Commission launched two new Industrial Alliances, which mostly act as pan-European discussion fora and do not benefit from direct funding or relaxed state aid rules: one on industrial data, edge and cloud, and one on processors and semiconductor technologies.

[2] Monitoring would be based on enhanced DESI reporting (see section 1.1.1).

structural funds.[1] It remains to be seen, however, whether actual (public and private) funding mobilised under those initiatives will suffice to close the huge digital transformation investment gap relative to the US and China – estimated by the Commission itself at around EUR 125 billion annually (EC, 2020c).

In February 2022, following earlier announcements by Commission president von der Leyen, the Commission proposed a European Chips Act, by analogy with US legislative initiatives (see section 3.1).[2] The European Chips Act package is based on three main pillars, to be financed with public and private investments of at least EUR 43 billion (in part by the rebranding of existing financial commitments) (EC, 2022a). First, investments under the Chips for Europe Initiative aim to strengthen EU semiconductor research, design and manufacturing capacities, and to develop training programmes and further understanding of global semiconductor value chains. Second, to better secure the supply of semiconductors and increase overall supply chain resilience the European Chips Act would support "first-of-a-kind" production facilities (i.e., going beyond the current state-of-the-art in the EU) that produce for Europe's own markets and other industrial players (in line with the Digital Compass 20 % target). And third, the Commission would set up coordinated systems for permanent monitoring of supply chain risks as well as for crisis response, which would be triggered in the case of significant supply disruptions. The envisaged crisis toolbox, governed by a new European Semiconductors Board, would include measures such as mandatory information gathering, the prioritisation of orders for critical sectors, common purchasing schemes and perhaps even export controls. The European Chips Act proposal has so far met with mixed reactions. Its critics question, for instance, whether (leading) EU chip firms are indeed capital-constrained; whether investing in semiconductors, especially in advanced chip manufacturing (a field where Europe is currently all but absent), will yield higher returns than in other digital sectors (from which part of the Chips Act's money is redirected); and whether the EU should join the global subsidy race to convince frontier chip firms such as TSMC, Samsung or Intel to set up cutting-edge fabs in Europe, rather than to leverage funds to build on current European strengths in chip research, manufacturing equipment and automotive applications. There are also worries about the risk of the Chips Act's crisis toolbox being used for protectionist purposes (see, e.g., Gross, 2022; Cerulus and Posaner, 2022).

Finally, in recent years, the US and EU have tried to deal with their concerns about (digital) China mostly in parallel. Their respective bilateral agreements with China – the Phase One agreement and CAI – have been frustratingly unsuccessful, even if they were arguably only incremental deals. And while both the US and EU are dissatisfied with the existing WTO multilateral trade and investment rulebook (including the rules on subsidies, SOEs and overall transparency), their views on the needed reforms have tended to diverge, especially on dispute settlement procedures (see Buysse and Essers, 2019). Perhaps the EU-US Trade and Technology Council (TTC), launched in June 2021 and first convened in Pittsburgh in September 2021, offers opportunities to develop greater mutual understanding and, ultimately, to increase transatlantic coordination and collaboration on shared global challenges that neither the US nor the EU can tackle alone (Bown and Malmström, 2021). In any case, the TTC's ten working groups cover a wide range of areas that all seem highly relevant in dealing with China's growing digital economy and the associated policy support.[3] Hopefully, adopting a more demanding rules-based stance rather than engaging in ad hoc pushbacks would help the US and EU to demonstrate that they primarily want to level the economic and technological playing field with China and to stand up for common principles, and not to repress China's development (Chimits, 2021). Far-reaching technological and value chain decoupling between the US and China and/or the EU and China risks splitting the world economy into separate competing blocs and would lead to large welfare losses for all, as confirmed by various simulation exercises (see, e.g., Cerdeiro *et al.*, 2021; US Chamber of Commerce and Rhodium Group, 2021; Felbermayr *et al.*, 2021).

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[1] For example, the Recovery and Resilience Facility requires that countries devote at least 20 % of the investments outlined in their National Recovery and Resilience Plans to supporting the digital transition.

[2] As well as the US and, of course, China, Japan and South Korea have also recently unveiled extensive semiconductor investment plans.

[3] The working groups include the following topics: technology standards; climate and clean tech; secure supply chains, ICT security and competitiveness; data governance and technology platforms; misuse of technology threatening national security and human rights; export controls; investment screening; promotion of small- and medium-sized enterprises' access to and use of digital tools; and global trade challenges. The post-summit joint statement highlighted commitments with respect to artificial intelligence, semiconductor supply chains, and non-market distortive trade policies, be it without explicitly mentioning China (EC, 2021e).

Conclusion

The relative size of China's digital economy and the number of ICT-related patent families registered by Chinese residents are quite impressive, considering that China is still an emerging economy. China's ICT sector is catching up quickly with that of the most advanced economies but, overall, does not (yet) rank among the global front runners. While China is at or close to the frontier for specific digital technologies such as 5G and cloud computing, this is not the case more generally.

Digitalisation has the potential to transform many traditional sectors. In this regard, China has shown itself to be a pace setter in e-commerce, digital payments (e-wallets), BigTech lending and the development of its central bank digital currency (the e-CNY), which is already in an advanced trial phase.

As the uncontested manufacturing powerhouse for ICT goods, China is also the world's largest end-user of semiconductors, the production of which is characterised by very complex and geographically dispersed value chains. China's main specialisation lies in the chip assembly, packaging and testing segment of the value chain and in the fabrication of less advanced chips, leaving it dependent on foreign chip designs, software and equipment as well as frontier chips manufactured abroad. This creates unwanted vulnerabilities for China. The semiconductor industry is therefore at the heart of China's industrial policy, with numerous plans and ample financial resources dedicated to its upgrading. Notwithstanding some successes, the results of these efforts have so far been modest.

China has great ambitions to become the world's leading (digital) innovator and is confident that it can reach this objective through its unique approach to industrial policy. The digital economy is now considered so strategically important that it can no longer escape the Chinese government's interventionist zeal, witness the regulatory clampdown on several of the country's technology giants in 2021. This tectonic shift in China's digital policy stance raises the concern that excessive government steering of the digital economy may stifle its growth.

Digital China is facing headwinds from an increasingly hostile international environment. Investment screening mechanisms put in place by the US and the EU make it harder for China to acquire Western technology firms with valuable knowledge. Continued technology tensions with the US, which have manifested themselves by means of export controls and other sanctions, further restrict China's access to much needed (semiconductor) technology. Risks of a further escalation are looming.

In addition, China's emergence as a rival in ICT has served as a wake-up call for advanced economies. Both the US and EU have stepped up their own digital/technological ambitions. It remains to be seen whether the future will bring more transatlantic coordination and collaboration in this field and whether engagements with China can move beyond ad hoc pushbacks. In any case, far-reaching technological and value chain decoupling between the US and China and/or the EU and China could end up splitting the world economy into separate competing blocs, resulting in large welfare losses for all.

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Conventional signs

%	per cent
e.g.	*exempli gratia* (for example)
EUR	euro
et al.	*et alia* (and others)
etc.	*et cetera*
i.e.	*id est* (that is)
RMB	renminbi
USD	US dollar
vs	versus

List of abbreviations

Countries or regions

BE	Belgium
DE	Germany
FR	France
IT	Italy
NL	Netherlands
SE	Sweden
EU27	European Union of 27 countries
UK	United Kingdom
CN	China
JP	Japan
KR	South Korea
US	United States

Abbreviations

ASE	Advanced Semiconductor Engineering
ASML	Advanced Semiconductor Materials Lithography
ATM	Automated teller machine
ATP	Assembly, testing and packaging
BIS	Bank for International Settlements
CAI	EU-China Comprehensive Agreement on Investment
CAICT	China Academy of Information and Communications Technology
CBDC	Central bank digital currency
CCP	Chinese Communist Party
CFIUS	Committee on Foreign Investment in the United States
CHIPS	Creating Helpful Incentives to Produce Semiconductors (Act)
(I-)DESI	(International) Digital Economy and Society Index
DRAM	Dynamic random access memory
EC	European Commission
ECB	European Central Bank

e-CNY	Digital yuan/renminbi
ECRA	Export Control Reform Act
EDA	Electronic design automation
EU	European Union
FABS	Facilitating American-Built Semiconductors (Act)
FDI	Foreign direct investment
FIRRMA	Foreign Investment Risk Review Modernization Act
FYP	Five-Year Plan
G20	Group of Twenty
GDP	Gross domestic product
I(C)T	Information (and communication) technology
IDDS	Innovation-driven development strategy
IDM	Integrated device manufacturer
IGF	Industrial Guidance Fund
IMEC	Interuniversity Microelectronics Centre
IMF	International Monetary Fund
IP	Intellectual property
IPCEI	Important Project of Common European Interest
IPO	Initial public offering
IPR	Intellectual property rights
ISIC	International Standard Industrial Classification of All Economic Activities
JCET	Jiangsu Changjiang Electronics Technology
M&A	Mergers and acquisitions
MERICS	Mercator Institute for China Studies
MFF	Multi-annual Financial Framework
MIC 2025	Made in China 2025
NAND	Not-and (Boolean operator)
OECD	Organisation for Economic Cooperation and Development
OSAT	Outsourced semiconductor assembly & test (company)
P2P	Peer-to-peer
PBOC	People’s Bank of China
PIIE	Peterson Institute for International Economics
R&D	Research and development
RISC-V	Reduced instruction set computer (architecture) – five
SIA	Semiconductor Industry Association
SME	Semiconductor manufacturing equipment
SMIC	Semiconductor Manufacturing International Corporation
SOE	State-owned enterprise
STI	Science, Technology and Innovation
TiVA	Trade in Value Added
TSMC	Taiwan Semiconductor Manufacturing Company

TTC	Trade and Technology Council
USTR	United States Trade Representative
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
ZTE	Zhongxing Telecommunication Equipment Company

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