Executive summary

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in electronic devices, semiconductors are essential to the production of many products, from smartphones to cars. Securing reliable supplies of semiconductors to safeguard the production lines of a range of industries has thus become an important policy goal, especially in the context of an increasingly confrontational international environment in which high-technology leadership is also associated with military power and geopolitical reach.

is highly concentrated, capital- and R&D-intensive, and particularly exposed to bottlenecks and political risks. High-end chip fabrication is centred in Asia, dominated by the duopoly of Taiwan's TSMC and South Korea's Samsung. In other parts of the supply chain, companies in the United States and Europe hold relative monopolies that have been leveraged for trade sanctions. e United States has taken steps to block the supply of chips and components to emerging tech giants in China, and to contain China's ambitions of building its own cutting-edge chip production capacities.

and Chinese investment poses a challenge to the European Union, which in response has set the goal of increasing European production beyond domestic demand. To increase its presence in this strategic and thriving sector, the EU needs a more targeted strategy that builds on its existing strengths while accommodating its relatively low domestic needs. Instead of investing public funds in a subsidy war over fabrication capacity, the EU should focus on inputs and chip design. However, no economy can hope to fully achieve independence in the sector and ensuring sustainable supply through diplomatic means should therefore also be a priority. Lastly, Europe's small role in global semiconductor production is symptomatic of shortcomings in the European environment for high-tech innovation. ese shortcomings should be addressed.

2 Semiconductors exposed to trade tensions

As digitalisation has entered into every part of the economy, the underlying digital technologies have become entangled in geopolitics. The association between technological leadership and geopolitical rivalry is nothing new. It is grounded in the assumption that technology can serve innovation in military equipment[1]. Meanwhile, digital technologies have created new security concerns for national governments over the handling of data, both civilian and classified, as government surveillance, hacking and cyber warfare increasingly threaten economic and political stability[2]. Given the centrality of semiconductors in digital technologies, some governments are reconsidering their position in relation to the technology frontier and their hold over the value chain of the semiconductors they consume.

Both the US and China see control over critical components in the networks that drive the digital economy as critical for cyber security[3]. This US-Chinese rivalry is at the heart of what has been described as a "technological cold war", in which leadership in high-end technologies is seen as key to obtain or maintain economic and political dominance[4].

In this context, the EU's own concerns about semiconductors intensified in early 2021 when global chip shortages (see section 4) led to production delays for important European industries[5], raising a question about of how the EU can defend its interests in an international environment again shaped by great-power politics[6]. In the global quest for technological leadership, the EU has an edge in digital regulation, notably through the "Brussels effect", or the capacity of EU regulations to shape global standards (Bradford, 2020), but relies on external partners for many digital goods and services. This reliance leaves the EU exposed to disruptions arising from the US-China rivalry.

2.1 The global semiconductor supply chain

Semiconductors perform a variety of functions in electronics. The most important are memory and logic functions. Chips consist of a semiconductor material (usually silicon), into which electronic components are embedded. Innovation in the sector focuses on adding more and more components onto increasingly small surfaces to increase processing performance and reduce energy consumption. This is expressed as 'node size', with smaller nodes in principle indicating the most advanced chips (though different firms' node sizes are no longer directly comparable). The latest smartphones use chips with 5 nanometre (5nm) nodes.

Creating nanoscale electronic components is extremely complex and requires high-tech equipment and materials. The complexity and capital intensity of the sector has led to specialisation and concentration of the manufacturing process, with only a few countries having sizeable production capacities: the US, Taiwan, South Korea, Japan, European countries and, increasingly, China.

1 President Obama's Council of Advisors on Science and Technology stated in a 2017 report on semiconductors: "To maintain its advantage, the US military needs access to leading-edge semiconductors that not all potential adversaries have" (Holdren et al, 2017).

2 For instance, cyber-attacks pose a systemic risk to financial services; see Demertzis and Wolff (2019).

3 A clear example is the sanctions on Huawei, over which the US is exerting pressure on its allies to exclude the Chinese company's components from their telecommunications networks (Barkin, 2020).

e geographic breakdown of production appears to have followed a gravitational pull towards its biggest consumers but, as we will argue, is also rooted in national industrial strategies. e semiconductor trade is mostly an Asian business (Figure 1). US rms, including Intel, Texas Instruments and Micron, dominate in terms of production volumes. However, their nished products mostly service the domestic market and therefore the US appears as a relatively small player in trade gures. Europe is both a minor producer and consumer of semiconductors.

Figure 1: Integrated circuits export and import values 2019, $ billions

Source: Bruegel based on Observatory of Economic Complexity.

e semiconductor sector has been a winner-takes-all innovation race (Hunt and Zwetsloot, 2020). To keep up, rms needed to attract top talent and to spend high amounts on capital items and R&D. For instance, in the last two decades, total semiconductor R&D spending has been close to 15 percent of the industry's global revenues annually – equivalent to the R&D spending in the pharmaceuticals and biotechnology sectors[7].

From a Chinese standpoint, external reliance exposes its ICT manufacturers to the risks of US extraterritorial sanctions. China therefore intends to boost the capacity of its domestic champion SMIC. But even though SMIC upgraded its manufacturing process to 14 nm nodes in 2019, the talent and capital needed to produce the next generation of chips (using a manufacturing process dubbed 10 nm or below) appears out of reach in the short to medium term (chapter 13, US National Security Commission on Artificial Intelligence, 2021). Notably, US trade restrictions have prevented Chinese foundries from acquiring some of the essential manufacturing equipment.

From a Western point of view, securing ICT supply chains has been a growing concern in recent years. The shortages in semiconductor supply in 2020 and 2021 increased the political pressure to ensure domestic manufacturing capacities. Although highly concentrated, chip production had kept pace with rising demand. But the current global shortages could signal lasting bottlenecks in the industry and help justify national measures to bring home manufacturing capacities.

3 A strategic sector defined by state support

Wherever the sector has developed significantly, it has been thanks to industrial success stories and also substantial state support. OECD (2019) measured distortions in the global semiconductor value chain from 2014 to 2018 and found government support to be particularly large (over $50 billion for the 21 large firms studied). Support took the form of below-market debt and equity, R&D support and investment incentives.

National governments have focused on the semiconductor industry since its beginnings in the late 1950s. After the Second World War, the invention of transistors paved the way for the breakthrough developments in the US of the integrated circuit (1959) and the microprocessor (1971). These inventions marked the birth of the Silicon Valley and the start of developments in line with Moore's law – that the number of transistors on a chip would double every two years – and led to the rise of Fairchild, Texas Instruments and Intel. The US government, and especially military and space agencies, strongly supported the industry, which was considered strategic (Danish Technological Institute, 2012).

US support was provided through research funding for universities, while public procurement ensured steady demand (Sauvage, 2019). Research collaboration between rivalling firms underpinned the creation of clusters in California. The US led the sector until it moved into mass production in the mid-1970s, opening opportunities for new entrants – most notably Japanese. The Japanese government successfully helped national companies catch-up with their US counterparts (Onishi, 2007). Complaining about unfair competition, US firms lobbied for restrictions on Japanese exports and more access to the Japanese market (Johnson, 1991). The ensuing trade dispute ended only in 1986, when Japan formally agreed to curb semiconductor exports and increase imports from the US. The agreement ultimately led to an increase in semiconductor prices which created an opportunity for South Korean and Taiwanese firms (Bown, 2020a).

Support schemes in different Asian countries were similar, with Taiwan providing a case study. The industry in Taiwan grew out of the political will to develop strategic industries in the 1980s (Office parlementaire d'évaluation des choix scientifiques et technologiques, 2008). Technological leadership was a goal intended to safeguard economic independence from China, and establishing domestic state-of-the-art foundries was an explicit government aim. A favourable investment environment was created with the development of industrial clusters (bringing together universities, industries and R&D centres), by ensuring education produced

For these historical industrial reasons and systemic characteristics, Europe is not a leader in the ICT sector. The European Commission's 2020 Industrial R&D Investment Scoreboard analyses the 2500 firms that invested most in R&D in 2019 – accounting for about 90 per cent of global privately funded R&D[16]. Although the EU accounts for 21 percent of the total (including 45 percent of global R&D investment in the automotive sector), it accounts for only 13 percent of total investment by ICT producers (which is, incidentally, the sector investing the most).

4 Semiconductor shortages and US-China rivalry

In late 2020, several factors led to a global shortage of semiconductors and a spike in prices. Demand was pushed by COVID-19-induced lockdowns, which saw increased sales of ICT goods and cloud-computing services[21]. New ICT products, including 5G compatible devices and video-game consoles, also contributed to the surge in demand. At the same time, Chinese
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ment has also successfully influenced Dutch ASML and Japanese Electron to stop sales to SMIC. ASML has a monopoly on extreme ultraviolet photolithography equipment required to manufacture high-end chips – below 14 nm nodes (Collins and Erickson, 2020). The US campaign to block sales to China started in 2018[36] and officially came to fruition in 2021 when the Dutch government granted ASML a licence to export some equipment to SMIC[37], but not cutting-edge equipment. SMIC should thus be able to build new foundries and manufacture widely-used chips (28 nm), notably in the automotive sector, but not in high-tech ICT products (below 14 nm).

Amid this unfolding 'tech cold trade war', there is risk of further digital decoupling. The confrontation has made both China and the US more eager to master the technology themselves. In November 2020, the Chips for America Act was introduced to the US House of Representatives, with a plan to put in place tax incentives and a trust fund to increase US manufacturing capacities[38]. Meanwhile, US restrictions are pushing Beijing to also invest in self-reliance in the sector[39]. In 2020, stockpiling of chips went in hand with stockpiling of chip-making equipment by SMIC. Although semiconductors were among the first targets of US tariffs against China, China has not imposed any trade barriers in the sector and continued to increase semiconductor imports from the US during 2020 (Bown, 2020a). Experts agree it will take years for China to be able to substitute banned US technologies or built capacities to fabricate cutting-edge chips domestically (Triolo, 2021).

Box 1: The Taiwan case

The Taiwan Semiconductor Manufacturing Company (TSMC) is of major importance for the global semiconductor industry. It has a 55 percent share of the semiconductor fabrication market (in the foundry business model) and produces most high-end chips. Global reliance on one firm in one country for such a crucial product involves risks. For example, the semiconductor industry is water-intensive, while Taiwan relies on a rainy season to replenish its water supplies for the drier winters. In 2020-2021, an unusually dry winter and spring led the government to cut water supplies to some companies[40]. This drought is not expected to affect TSMC, but Taiwan's exposure to climate and natural disaster risks provides a justification for diversification of production locations.

TSMC is of major importance to the Taiwanese economy. It is the country's biggest company by market capitalisation, accounting for a third of local stock market value. Revenue from semiconductors, in which TSMC is dominant, is equivalent to 15 percent of Taiwanese GDP[41]. The reliance of the world economy on TSMC for high-end chips exposes Taiwan to political pressure from foreign powers but also gives it some political leverage. In January 2021, amid the shortage, Taiwan used TSMC as a bargaining chip when seeking help from Germany

36 See Alexandra Alper, Toby Sterling and Stephen Nellis (2020) 'Trump administration pressed Dutch hard to cancel China chip-equipment sale: sources', *Reuters*, 6 January, available at https://www.reuters.com/article/us-asml-holding-usa-china-insight-idUSKBN1Z50HN.

37 See Frank Chen (2021) 'China takes first baby step towards chip self-reliance', *Asia Times*, 23 March, available at https://asiatimes.com/2021/03/china-takes-first-baby-step-towards-chip-self-reliance/.

38 H.R.7178; see https://www.congress.gov/bill/116th-congress/house-bill/7178.

39 See *Bloomberg News* (2021) 'China Stockpiles Chips, Chip-Making Machines to Resist U.S.', 2 February, available at https://www.bloomberg.com/news/articles/2021-02-02/china-stockpiles-chips-and-chip-making-machines-to-resist-u-s.

40 See Debby Wu and Cindy Wang (2021) 'Taiwan Cuts Water Supply for Chipmakers as Drought Threatens to Dry Up Reserves', *Bloomberg*, 24 March, available at https://www.bloomberg.com/news/articles/2021-03-24/taiwan-raises-red-alert-over-water-cuts-supply-for-chipmakers.

41 See Cheng Ting-Fang and Lauly Li (2021) 'Taiwan's economy feels heat as TSMC feeds global chip boom', *Nikkei Asia*, 9 February, available at

to secure COVID-19 vaccine supplies[42].

TSMC is also relevant to Taiwan's sovereignty. Mainland China considers Taiwan to be part of its territory and has never renounced the threat of force to carry out its reunification plans. China's clampdown in Hong Kong and more Chinese military exercises near the Taiwan Strait have fed fears that the increased pressure on Taiwan may soon lead to the annexation by force of the democratic island[43]. Some observers believe that the global imperative to keep TSMC plants running helps protect Taiwan from a military invasion that could halt production[44]. Beyond military threats, the semiconductor industry allows Taiwan to be an essential trade partner to China, offsetting its economic reliance on China (Lee and Kleinhans, 2020). China absorbs over 25 percent of Taiwanese exports, nearly 40 percent of which are semiconductors[45].

Chinese company Huawei, itself the subject of disputes between the US and China, is TSMC's second largest customer behind Apple, accounting for over $5 billion of TSMC's revenues in 2019[46]. Huawei subsidiary, Hisilicon, design its own chips but outsources fabrication to TSMC. Hisilicon itself does not rely on US inputs, but TSMC does, and because of US sales restrictions has had to curb sales to Huawei. TSMC could have sourced required inputs from non-US suppliers, but chose to comply with US sanctions (Bown, 2020b). In the long run, Western countries, most notably the US, are pushing to diversify their supply of cutting-edge chip, most notably by reshoring production. But as TSMC is expected to remain ahead in terms of innovation and production capacities, the semiconductor industry provides an incentive for the US, and others, to defend Taiwanese independence (Lee and Kleinhans, 2020). Retaining chip leadership will remain a major asset for Taiwan, even if production is done at facilities beyond the island: TSMC is also working to expand production capacities in the United States and Japan, for example[47].

4.2 US-China rivalry and its impact on the EU and third countries

High-technology products that cannot easily be substituted provide easy targets for trade sanctions in the semiconductor sector. In its quest to limit the rise of Chinese firms, the US has targeted bottlenecks beyond its own jurisdiction (the US accounts for only 5 percent of China's chip imports; Bown, 2020a). The US has done so by banning the sale to Chinese firms of products in which US know-how makes up at least 25 percent of their value, but also by pressuring allied governments to implement their own export bans[48].

These restrictions are costly for all affected firms that end up cut off from the world's

42 See Reuters (2021) 'Taiwan asks Germany to help obtain coronavirus vaccines', 28 January, available at https://www.reuters.com/article/us-health-coronavirus-taiwan-idINKBN29X11P.

43 See Oriana Mastro (2021) 'The Taiwan Temptation: Why Beijing Might Resort to Force', Foreign Affairs, July/August, available at https://www.foreignaffairs.com/articles/china/2021-06-03/china-taiwan-war-temptation.

44 See Raymond Zhong (2020) 'In U.S.-China Tech Feud, Taiwan Feels Heat From Both Sides', New York Times, 1 October, available at https://www.nytimes.com/2020/10/01/technology/taiwan-china-tsmc-huawei.html.

45 Source: The Observatory of Economic Complexity; see https://oec.world/en/profile/country/twn?yearSelector1=exportGrowthYear25.

46 See Cheng Ting-Fang and Lauly Li (2020) 'TSMC halts new Huawei orders after US tightens restrictions', Nikkei Asia, 18 March, available at https://asia.nikkei.com/Spotlight/Huawei-crackdown/TSMC-halts-new-Huawei-orders-after-US-tightens-restrictions.

47 See Sherisse Pham (2020) 'Taiwan chip maker TSMC's $12 billion Arizona factory could give the US an edge in manufacturing', CNN Business, 15 May, available at https://edition.cnn.com/2020/05/15/tech/tsmc-arizona-chip-factory-intl-hnk/index.html.

48 See US International Trade Administration, 'China - Country Commercial Guide', available at https://www.trade.gov/knowledge-product/china-us-export-controls (accessed June 7, 2020).

foremost semiconductor consumer, China, which accounts for half of global chip sales[49]. The global semiconductor industry association (SEMI) reported that bans on the export of US-origin designs and equipment to Huawei and affiliates, put in place in mid-May 2020, had already resulted in $17 million in lost sales by mid-July 2020[50]. In December 2020, European executives and diplomats voiced concerns that trade restrictions tend to favour US firms because some are granted licences to sell to Huawei or SMIC, while EU competitors are kept out of the Chinese market[51]. Samsung and Sony have also been granted licences for non-5G related components[52].

The long reach of US export bans underlines the political risks to the global industry, most notably from US policymaking. Some countries, such as South Korea which has so far managed to balance its reliance on the US for security and on China for trade, may be forced to choose sides in what may be become an increasingly expensive high-technology rivalry[53].

5 The EU amid the digital decoupling push

European companies could be casualties of US measures that aim to limit technology transfers to China. Most importantly, sanctions could disrupt the production of semiconductors, leading to economic damage for European consumers, as shown by the effects of the shortages in the automotive sector in 2020. Cerdeiro et al (2021) found that, because of the high share of foreign value added in high-tech exports (notably from China and ASEAN countries), technological decoupling would be detrimental to global productivity and innovation in the sector. In their worst scenario they found that technological decoupling could lead to significant GDP losses – assessed at 4 percent of GDP for the EU, South Korea and China.

dubbed 'Industry 4.0', is crucial to ensure European competitiveness in the fourth industrial revolution[55]. Digitalisation is of major importance to the automotive sector, which employs around 6 percent of European workers and represents more than 7 percent of EU GDP. Cars are becoming 'computers on wheels' and, especially in a potential self-driving future, semi-conductors will become a core part of automotive technology. Digital technologies are also key for the transition to a climate neutral and resilient economy.

In March 2021, when launching the 'digital decade' initiative, the Commission considered digital technologies as increasingly strategic and argued that the coronavirus pandemic and the lockdown context has provided an impetus for strategic action in the sector[56]. The digital decade would be based on digital transformation targets to be achieved by 2030[57], including a alliance will look like is at the time of writing not clear. Public subsidies would come either from member states under the IPCEI, or from EU funds dedicated to digital transition under the post-COVID-19 Recovery and Resilience Facility. But there is no guarantee the total investment target, which also relies on future private investment, will be reached. While it is not possible to directly compare the subsidy regimes of di erent countries, announced public investment in the US and China is much larger. e Biden infrastructure plan includes or China. e other is to invest to realistically compete in an industry in which high-end pro

Europe’s constraints in implementing industrial policy mean that industrial policy projects rely on national governments. Whether the approach of white-listing sectors for national state aid results in an e ective targeted industrial strategy is questionable, as it relies heavily on national initiatives, while strategic collaboration between EU countries has not yet happened. In this respect, the industrial alliance proposed by the European Commission in 2021 is encouraging but its objectives, members and resources are still largely unde ned. e lack of deep European venture capital markets also impedes the growth of European start-ups. Furthermore, investment screening and protection against technology transfers remains a national prerogative[67]. Only 18 of the 27 EU countries currently have investment screening mechanisms, and the decision on whether or not they greenlight transactions depends entirely on national governments[68]. In all these areas of foreign and trade policy, the advantages of a common policy seem clear. If the EU wants to become a major international player and to be able to protect its economic interests against Chinese (and American) in uences, increased centralisation of these policy decisions at European level is necessary.

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