December 2021 · Jan-Peter Kleinhans & John Lee

China's rise in semiconductors and Europe

Recommendations for policy makers

Stiftung
Neue
Verantwortung

MERICS
Mercator Institute for China Studies

Executive Summary

Semiconductors are on the mind of many European policy makers, not least because of the intensifying US-China technology rivalry and the chip shortages that forced most European car makers to temporarily stop production from 2020. As a result, the European Commission is working on an EU Chips Act, a draft of which is scheduled to be ready in mid-2022. Europe's semiconductor industry has not received this level of attention from policy makers in a long time, and the EU has now a window of opportunity to substantially invest in its semiconductor ecosystem and strengthen international partnerships. The only questions are what, how and where?

In our previous report of June-2021, "Mapping China's semiconductor ecosystem in global context", we argued that Europe is already highly dependent on Chinese companies in certain value chain steps and that this dependence will likely grow over the short-term future. As China is now considered from a European viewpoint to be an "economic competitor" and "systemic rival" as well as a "cooperation partner", these dependencies must be assessed across different dimensions of the national interest: national security, technological competitiveness and supply chain resilience. Based on these assessments, we argue that EU's forthcoming semiconductor strategy should include three focus areas.

First, substantially investing in EU's dwindling chip design ecosystem, focusing on improving conditions for start-ups, small and medium-sized enterprises and spin-offs from research institutions. This should include lowering entry-barriers to chip design, investing in chip design infrastructure and improving access—in terms of speed, level of bureaucracy and amount—to funding, private and public equity. China already has a substantially stronger chip design ecosystem than Europe in several areas and can scale faster due to heavy investment in chip design by China's hyperscalers, Internet of Things and mobile technology companies. Under these conditions, Europe will increasingly depend on Chinese designed chips.

Second, Europe needs to strengthen its position in back-end manufacturing (assembly, test and packaging), going beyond existing strengths in research & development. While front-end fabs from leading companies such as Intel, TSMC or Samsung receive much attention from policy makers, the concentration in Asia of back-end capacity has direct national security implications for Europe. Furthermore, back-end manufacturing, especially emerging advanced packaging processes, are increasingly important to the development of high performance and energy-efficient chips. China has significant global market share in back-end manufacturing, exposing Europe to a variety of risks.

Third, Europe needs to strengthen its collective capacity to continuously map and assess the global semiconductor value chain, to understand interdependencies, evaluate bottlenecks and identify potential shortages over the long-term. Ad hoc assessments are not a sound basis for strategic planning for this highly complex and intertwined industrial value chain. One possibility would be to increase the resources and scope of the newly established Observatory for Critical Technologies but just as important would be strengthening partnerships with like-minded partners, notably the US and East Asian economies.

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Introduction

The global semiconductor shortages since 2020 have led to significant spillover damage for various industry sectors. Together with the ongoing US-China competition in critical technologies, this has brought the semiconductor industry to the attention of many policy makers. Several European member-state governments and the European Commission are devising long-term strategies to strengthen their domestic semiconductor industries, manage national security risk and improve the resilience of this critical and transnational value chain.

Semiconductor manufacturing, especially subsidizing the construction of front-end fabrication plants ("fabs"), is at the core of several governments' strategies, including that of the European Union (EU). However, to address the EU's increasing dependence on the fast growing semiconductor ecosystem of China, a country that has been defined in EU strategic policy as an "economic competitor" and "systemic rival", merely subsidizing semiconductor manufacturing will not suffice.[1] Instead, the EU needs to take a whole-ecosystem approach that considers all steps of the value chain and is not confined to a narrow set of policy prescriptions, such as the subsidy measures that have dominated the policy discussion to date. This cannot be done solely by strengthening Europe's ecosystem but needs to utilize strategic partnerships, especially with East Asian economies that play a critical role in the semiconductor value chain today, such as Taiwan, South Korea, Japan, Singapore or Malaysia.

Our previous report of June 2021 ("June report"), *Mapping China's Semiconductor Ecosystem*, assessed China's semiconductor industry across three strategic dimensions of the national interest: technological competitiveness, national security and supply chain resilience.[2] Following on from these assessments, in the present paper, we argue that European policy makers should include in semiconductor strategies three areas that are neglected in current debates but crucial to Europe's technological competitiveness and security: chip design; assembly, test and packaging (ATP); and increased visibility and tracking of the whole value chain.

In the first section, we review China's development of significant chip design capabilities, including the competitive advantage of Chinese hyperscalers, mobile and consumer electronics companies that are all heavily investing in their own chip design units and Chinese start-ups. Potentially, this trend will result in Europe becoming increasingly dependent on Chinese-designed chips in the absence of a strong European chip design sector, with potential national security implications and negative impacts on the competitiveness of European firms in industries that depend on semiconductors.

In the second section, we assess the link between the value chain's final manufacturing step (ATP) and national security, as this step in the value chain provides the most opportunities for a malicious actor to compromise a chip. The EU depends heavily on ATP capacity within China, as Chinese companies have gained significant market share in this labor-intensive process step. We argue that this dependence has potentially significant national security implications and, furthermore, threatens the EU's long-term technological competitiveness in the semiconductor industry as a whole.

In the third section, we do not focus on a particular step in the value chain but rather on the importance of value chain transparency as the first step in strengthening the resilience of the global semiconductor industry. Europe needs to invest in its own capacity to understand and track this dynamic supply chain, including in co-operation with like-minded partners. A better awareness of developments within the global semiconductor value chain is especially relevant not only in periods of increased geopolitical and trade tensions with China but also in light of natural disasters that are increasing in frequency and severity and will continue to disrupt the semiconductor value chain, in addition to pandemic-related lockdowns, human error and unpredictable surges in market demand.

In each of the three sections, we provide recommendations for European policy makers on how to strengthen the EU's semiconductor ecosystem and thus protect European interests with respect to China's growing prominence in the global semiconductor industry, and the growing international political pressures that stem from US-China competition. We conclude by revisiting the larger geopolitical context and the stakes involved in this most foundational of technologies.

1. Chip design: setting the course upstream in the value chain

Chip design is the step in the semiconductor value chain that involves the highest value added (50%), and therefore, the greatest proportionate revenue capture, compared with wafer fabrication (24%) and assembly, test and packaging (6%). So-called "fabless" chip design companies typically spend more than 25% of their revenue on research and development.[3] Pursuit of performance and efficiency gains has required chip designs to become increasingly specialized and application specific. General-purpose processors are no longer suitable for compute-intensive tasks such as machine learning, network traffic management and many others.[4] This increases the importance of the chip design step in the semiconductor value chain as a whole. Historically, the US has had the strongest chip design ecosystem, with U.S. chip design companies accounting for 64% of the global market.[5] Chip design is talent-intensive and relies on close business relationships with semiconductor fabrication firms that manufacture the chips. In this section, we explore how China's quickly growing and vibrant chip design ecosystem creates potential challenges for Europe's technological competitiveness and national security.

What China is doing

Although the proportion of revenue that Chinese chip design firms spend on R&D is comparable to their foreign counterparts, Chinese firms' typically small revenues next to global industry leaders like the U.S. chip design giant Nvidia mean much smaller numbers.[6] However, this picture is changing significantly with the entry of cash-rich Chinese hyperscalers (large internet platform-based service providers that diversify into other verticals, such as Baidu, Alibaba and Tencent) in the chip design market and the increasing availability of state-led and private venture investment,[7] as reflected in the growing list of cutting-edge chip designs being announced by Chinese firms (Table 1 below).[8]

In terms of the general business environment for Chinese chip design firms, they are well positioned to exploit the relatively low barriers to entry and high revenue returns of this production step, given the ready availability of in-house and venture capital, a large and growing domestic talent pool, and the concentration in China of growing industries that require new semiconductor designs.[9] In the automotive sector, for instance, according to one estimate, Chinese car brands will offer L1–L3 autonomous driving functions in 75% of their vehicles by 2030.[10] This creates a large market for Chinese firms designing specialized processors for cars, examples of which are given at Table 1 below.

Chip design start-ups like Cambricon and Enflame are targeting China's growing market for artificial intelligence (AI) applications. Internet platform giants such as Baidu, Alibaba and Tencent, like their U.S. counterparts Google, Amazon and Face-book, are designing their own chips to optimize delivery of digital services such as cloud computing and to exploit their advantages in accumulated data sets that can support AI training. Even China's large home appliance manufacturers are investing in chip design start-ups and in-house units, aiming to improve their own products and so become more competitive.[11] By one estimate, the value of China's chip design market grew 23% from 2019–2020, and will grow 20% over 2021–2026, even allow-ing for the effects of the global coronavirus pandemic.[12]

Most of the Chinese chip design sector's products remain, in performance terms, in the middle to lower end of the global market. However, the resources now invested are resulting in a growing number of high-performance designs that will support Chinese firms' competitiveness across an increasing range of industries, especially within China's domestic markets but also increasingly in international markets. By one estimate, whereas five years ago Huawei was the only Chinese firm designing cutting-edge chips, today "maybe 10 or 12 companies in China... can do designs at 5nm (cutting-edge process nodes) moving to 3nm next year or after that."[13] Table 1 below provides a partial list of chip designs announced by Chinese firms during 2021, with associated industry applications.

Company and chip model	Function	Industry sectors
Alibaba: Yitian 710	Network performance	Cloud computing
Tencent: Zixiao	Network performance	Cloud computing
Tencent: Xuanling	AI-enabled image and natural language processing	Image recognition, voice and translation assistance
Tencent: Canghai	Video format conversion	Visual media
Baidu: Kunlun 2	Network performance, AI-enabled processing	Cloud computing, image recognition, voice and translation assistance, automotive
Cambricon: Siyuan 290	AI training and processing acceleration	(multiple)
Enflame: CloudBlazer T20	AI training	(multiple)
SiEngine: SE1000	Intelligent connected vehicle services	Automotive
Jingjia Micro: JM9	Graphics processing	Desktop computing
Horizon Robotics: Journey 5	Autonomous driving (Edge AI) SoC	Automotive

Table 1:
Selected chip models and potential industry applications, 2021 announcements

U.S. export controls targeting specific Chinese firms have damaged some business lines for these companies and the market share of China's leading chip design house (Huawei's HiSilicon) but have not had an observable negative impact on China's larger chip design ecosystem.[14] They might boost this ecosystem by dispersing the capital and human resources previously amassed by HiSilicon and incentivizing large Chinese companies to invest in domestic firms that are trying to plug the capability gaps Chinese industry suffers from elsewhere along the value chain.[15]

Chinese industrial policy expressly aims to use demand generated by China's larger economy to drive the development of Chinese firms' capabilities in chip design and other semiconductor value chain segments.[16] As observed in the June report, this is a "two-track approach of targeting mature markets and emerging technologies," aimed at supporting Beijing's goals for strategic emerging sectors and digitalization of China's wider economy.[17] The size and growth of China's markets continue to pull in foreign industry leaders, despite rising risk from foreign export and investment controls alongside growing political pressure within China to conform to Chinese national development priorities.[18]

For example, in October 2021, the Japanese firm Rohm, a leader in power management semiconductors (a category in which European firms are still competitive), announced a joint venture with a Chinese firm to design and build silicon carbide-based power modules. The partnership targets China's fast-growing electric vehicle sector, with mass production scheduled to start in 2022.[19] Silicon carbide is among several compound materials that represent a potential new frontier in advancing semiconductor performance and have been identified by the Chinese and U.S. governments as priorities for strategic technology development.[20]

Chinese firms are also focused on employing RISC-V open-source instruction set architecture.[21] This is a non-proprietary body of intellectual property (IP) that provides an alternative "blueprint" for customized chip design to the proprietary architectures owned by the United Kingdom (UK) and U.S. firms ARM, Intel and AMD. RISC-V's development is promoted by a transnational industry association that relocated from the US to Switzerland expressly to avoid U.S. export controls.[22] More than half of the RISC-V association's board of directors are connected to Chinese companies and research institutions.[23]

Chinese firms and institutions have been developing RISC-V IP (such as processor cores) that can be licensed by other actors as a basis for their own chip designs.[24] Chinese actors have also announced RISC-V-based chip designs that meet performance benchmarks at the global technical frontier.[25] Chinese authorities are promoting use of RISC-V through such measures as sponsoring industry consortiums and subsidizing RISC-V based chip development.[26]

For cutting-edge chips, Chinese fabless companies rely on foreign foundries, such as TSMC in Taiwan and Samsung in South Korea, for contract manufacturing. However, these foundries are facing growing pressure from U.S. political and regulatory actions to cut off their Chinese customers. How effective such pressure will be in restricting the development and market expansion of Chinese chip design firms depends on whether the U.S. government adopts wider reaching measures.[27] At present, fabrication firms like Taiwan's TSMC and South Korea's Samsung (the only two entities worldwide that are capable of manufacturing the most recent generations of semiconductors) have retained Chinese customers that are not individually subject to U.S. export controls.

How this affects Europe's competitiveness and security

The growing and relatively advanced Chinese chip design capabilities described above have potentially far-reaching implications for Europe's technological competitiveness and member states' national security. China's chip design ecosystem will continue to grow much faster than Europe's[28] because of China's vibrant chip start-up scene and its vertically integrated companies, such as hyperscalers, mobile and Internet of Things (IoT) companies all heavily investing in in-house chip design units.

Technological competitiveness: It will potentially be harder for European semiconductor companies to compete with internal chip design units of vertically integrated companies in the Chinese market. The domain expertise of a vertically integrated company is utilized during chip design to gain a competitive advantage.[29] Chinese hyperscalers (Alibaba, Tencent), smartphone companies (Huawei; BBK Electronics, the conglomerate behind OnePlus, Oppo, Vivo and Realme) and consumer electronics companies (Xiaomi) can utilize their domain expertise to develop highly specialized, high-performing and efficient chips, making it potentially harder for companies without such chip design capabilities to compete. Additionally, Chinese firms might favor domestic chip design solutions over foreign ones, as Chinese firms can work more efficiently with local firms in product co-design and manufacturing because there is less risk of interruption by foreign export controls. The rising "computerization" of a growing range of industries is allowing Chinese firms with access to chip design capabilities to expand horizontally into new sectors, such as automotive. Other factors being equal, these Chinese firms will increasingly be able to outcompete foreign rivals that lack access to a comparable chip design ecosystem.

National security: Increasingly sophisticated chip design capabilities within China do not impact only Europe's technological competitiveness. Those capabilities are utilized by the Chinese military for supercomputers simulating missile trajectories, as one example.[30] Chinese industry's development of chip design capabilities

has direct military utility, because this gives China's military access to potentially more powerful and efficient chips, which is of concern to the U.S. government and requires consideration by the EU and member states in defense planning.[31] Leading Chinese firms such as Alibaba and Baidu are partnered with Chinese state-owned conglomerates to provide big data analysis, cloud computing, spatial navigation and other chip design-driven capabilities for military purposes.[32]

What Europe should do

Except for Europe's incumbent semiconductor companies such as Infineon, NXP and STMicroelectronics and telecommunication vendors Ericsson and Nokia, Europe's chip design ecosystem is lacking. European car manufacturers were slow to invest in their own chip design capabilities,[33] and the EU lacks large consumer electronics and mobile technology companies with the resources and incentives to develop such capabilities, or that can provide the market demand for other companies to them. For these reasons, Europe needs to invest substantially in its chip design start-ups to grow an ecosystem long-term.

- **Provide more, quicker and less bureaucratic funding to chip start-ups** by expanding the *European Innovation Council's* (EIC) Accelerator with a semiconductor-specific stream in the work program; by evaluating and then streamlining the bureaucratic process for and general design of *Important Projects of Common European Interest (IPCEI)* to make them quicker and more accessible to small- and medium-sized enterprises (SMEs); by making funding under the *Key Digital Technologies (KDT)* Partnership[34] more accessible for start-ups and SMEs (in KDT Partnership's predecessor the *European Components and Systems for European Leadership (ECSEL) Joint Undertaking*, less than a quarter of the participating companies were SMEs[35]); by i*ncentivizing spin-offs from research and technology organizations (RTOs) and universities* through more favorable license costs (RTOs have an economic incentive to receive high license fees, but these high spin-off costs make the start-up less attractive for investors).

- **Invest in chip design infrastructure and lower barriers to entry**. Chip design is always based on a specific manufacturing process, making it significantly more complex and expensive than traditional software development. That is why start-ups often depend on universities and RTOs for significantly lower license fees for chip design software and access to fabs (e.g., through EUROPRACTICE[36] and ASCENT+[37]). Lowering entry barriers to chip design should be a key policy goal.

- **Invest in open-source architectures, such as RISC-V**. The RISC-V ecosystem is gaining a lot of momentum because of its openness, its viability for many different applications and sectors (from automotive to AI, IoT and high-performance computing) and the looming acquisition of ARM by Nvidia (which, from the viewpoint of most other chip design firms, threatens to transfer ownership of the underlying IP to a competitor). Some of Europe's semiconductor companies and RTOs,[38] industry associations[39] and member states' research ministries[40] recognize this window of opportunity for Europe to position itself as a frontrunner in this new ecosystem. The RISC-V ecosystem is still in its infancy when compared to ARM's rich IP ecosystem, but European semiconductor companies and RTOs are actively developing RISC-V chips and IP. To strengthen Europe's presence in this field and become a frontrunner, especially in relation to China, more coordination and long-term investment are necessary. This includes **dedicated research funding through Horizon Europe, industry alliances** that focus on developing RISC-V for specific verticals (such as automotive and industrial IoT) and more **coordination on the European level**. A continuous mapping of the RISC-V IP landscape in collaboration with industry, similar to the European Commission's *Rolling Plan for ICT Standardization*,[41] could provide a gap analysis and better coordinate different industry and research efforts.

2. Back-end manufacturing: a neglected process step with high potential

Historically, back-end manufacturing (assembly, test and packaging) was a labor-intensive value chain step that involved limited innovation, small value added and low profit margins. Accordingly, ATP was predominantly outsourced to Asian countries such as Taiwan, China and Malaysia (thus, the alternative acronym OSAT, "outsourced semiconductor assembly and test"). In the past, packaging simply meant that after the wafer was fabricated (front-end manufacturing), the individual chips were cut out of the wafer, tested and encapsulated so they could be soldered into smartphones, cars or any other device. However, because of the exploding costs of progressing cutting-edge wafer fabrication to continually increase performance, companies started investing in innovating new packaging processes, such as heterogeneous integration and 3D stacking. Over the past several years, it has become clear that these "advanced packaging" approaches play a crucial role in ensuring energy efficiency and chip performance. With the increased level of innovation in advanced packaging approaches comes a potential increase in value added and profit margins for this step in the value chain. In this section, we provide an overview of China's role in back-end manufacturing processes and why Europe should invest in its own packaging capabilities.

What China is doing

ATP is the one production step in the semiconductor value chain where Chinese firms hold a globally significant market share (Figure 1 below).[42] More than 60% of global ATP capacity is located in Taiwan and China, including Western companies' back-end fabs located in these jurisdictions.[43] In 2019, China was the biggest (25%) market worldwide for semiconductor packaging materials.[44]
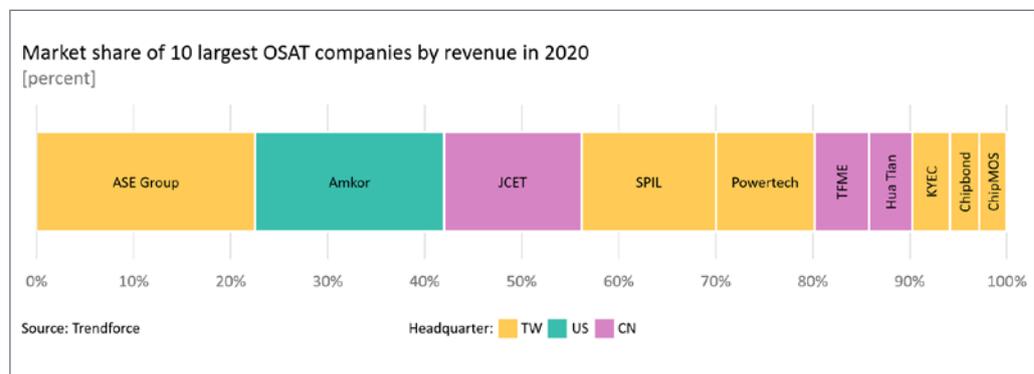
Figure 1:
Market share of
world's 10 largest
OSAT firms, 2020

"Advanced" packaging techniques still account for a minority share of revenue for Chinese OSAT leaders, estimated at around 20% in 2019.[45] However, these firms are conducting significant R&D activity in advanced techniques and beginning to deploy them in business operations.[46] JCET, for example, now the third largest packaging firm globally by sales, employs advanced techniques such as 2.5D and 3D (hetero-geneous) packaging.[47] These techniques are being utilized by Chinese chip design firms in delivering cutting-edge products, showing synergies between technical progress in different production steps within China.[48] The three largest Chinese OSAT firms (Figure 1 above) are all reportedly planning secondary public offerings to raise capital to invest in capacity expansion and advanced packaging techniques.[49]

Chinese OSAT companies will also benefit from local concentration of the printed circuit board (PCB) industry, which is increasingly closely related to the semiconductor value chain's back-end, as performance demands in consumer electronics drive PCB vendors to pursue miniaturization.[50] The global PCB supply chain is now concentrated in China, and Chinese suppliers are growing their market share.[51] In 2019, China accounted for more than half the global market for chemicals used in PCB production and was the fastest-growing market followed by Taiwan and South Korea.[52] Taiwanese PCB industry leaders are expanding operations in mainland China, in tandem with local growth in manufacturing of consumer electronics, self-driving cars, network equipment and other products.[53]

The PCB industry is central to security concerns surrounding the potential for the semiconductor value chain's back-end to be exploited for espionage. In 2018 and 2021, Bloomberg reported that an additional chip had been installed on server moth-erboards manufactured in China and was found to be transmitting data to China from networks in U.S. companies and government agencies.[54] Although the accu-racy of both reports was denied by the U.S. firms involved and widely criticized by experts, the reports highlight the potential implications for corporate and national security of outsourcing to and relying on Chinese ATP capacity.[55] The PCB industry's strategic importance was noted in the Biden administration's 2021 semiconductor supply chain review.[56]

Advanced packaging is being promoted by Chinese industry experts and probably receiving attention at senior levels of China's political leadership as an alternative to the increasing technical difficulty of shrinking fabrication nodes that is implied by Moore's Law.[57] Such "node shrinkage" is a critical bottleneck for China's semicon-ductor industry, and advanced packaging is being pursued as an alternative pathway for improving performance, for example, at China's leading foundry SMIC.[58] U.S. ex-port controls against SMIC, and SMIC's inability to acquire certain advanced ma-chinery from Dutch equipment maker ASML, has increased the urgency for Chinese industry to develop such alternative technical pathways, simply to keep pace with global technological progress and mitigate risk from foreign measures aimed at de-coupling from China's economy and supply chains.

How this affects Europe's competitiveness and security

As of 2019, Europe had less than 5% of the global ATP capacity and, like the rest of the world, heavily depends on back-end manufacturing in China.[59] This comes with potential national security and technological competitiveness risks for Europe.

National security: Compared to the two previous process steps, chip design and wafer fabrication, packaging processes provide a resource-efficient (skills, cost, time) attack vector to compromise a chip to implement a "kill switch" or hardware backdoor.[60] Although such hacking of a computer on the chip level with a hardware backdoor is significantly more resource-intensive than utilizing software exploits, the advantage of hardware backdoors is their persistence and that they are significantly harder to detect. As government agencies and the military will unavoidably rely to some extent on commercial semiconductor manufacturing, and thus untrusted sources, ensuring supply chain security and trustworthiness of fabs (front-end and back-end) becomes a challenge. One strategy is "Split Manufacturing": relying on untrusted foundries for wafer fabrication but using trusted back-end fabs for assembly, test and packaging.[61] This also means that expanding Europe's wafer fabrication does not alleviate the national security threat if those wafers are then shipped to China for assembly, test and packaging.

Technological competitiveness: Advanced packaging processes play a critical role in increasing the performance and energy efficiency of future chips. Chinese companies are not yet at the forefront of advanced packaging technology, but they are investing in this area, and the Chinese ATP ecosystem has high potential for upgrading. Senior-level Chinese authorities are likely focused on advanced packaging as a strategic priority: for example, senior Chinese economic planners were briefed in mid-2021 on "potential disruptive technologies" for advancing semiconductor performance in the "post-Moore era."[62] If competitive advantage in future chip manufacturing is increasingly linked to advanced packaging techniques such as heterogeneous integration, European manufacturing will also need to compete (and thus invest) in these areas.

What Europe should do

European RTOs such as imec in Belgium, CEA-Leti in France and Fraunhofer in Germany have extensive expertise in advanced packaging and well-established research ties with industry. Similarly, European manufacturing equipment vendors such as ASM International, Aixtron, BESI and AT&S have leading positions in the ATP equipment market. What is lacking is actual packaging capacity, which has been almost entirely outsourced to East and South Asian economies.

- **Use IPCEI and the proposed Semiconductor Fund to invest in packaging capacity in Europe.** Although European policy makers have focused a lot on subsidizing front-end fabs, as articulated in the *Joint Declaration on Processors and Semiconductor Technologies*[63] in December 2020 and the *2030 Digital Compass*[64] in March 2021, future subsidies and industrial policy measures should also target back-end manufacturing. The relevance of ATP capacity in Europe has been recognized in the soon-to-be-established (at the time of writing) *European Alliance on Processors and Semiconductor Technologies*.[65]

- **Diversify ATP capacity geographically through international partnerships.** Europe will continue to rely substantially on back-end manufacturing in Taiwan and China due to lower labor costs and economies of scale. However, other countries, such as Malaysia and Singapore, are already important ATP regions. Infineon, NXP and STMicroelectronics have substantial back-end manufacturing in Malaysia. This provides an opportunity for Europe to strengthen these partnerships through strategic investments and research collaborations to diversify back-end manufacturing geographically and strengthen the resilience of the back-end manufacturing value chain. At the same time, European policy makers must be aware of local conditions with potential security implications, for example, the Malaysian government's institutionalized collaboration with Huawei on cybersecurity issues.[66]

3. Value chain resilience: visibility through multilateral partnerships

The global chip shortages that started in 2020 put into question the health and resilience of the semiconductor value chain at the transnational level. With high levels of division of labor between countries, long manufacturing cycle times and economic pressure to run fabs close to full capacity, semiconductor manufacturing is susceptible to external shocks and does not cope well with demand surges.[67] The severe spillover damage to other sectors led to a flurry of attention from policy makers in Brussels, Washington DC, Tokyo, Seoul, Taipei and many other capitals. From task forces to consultation processes and information requests, governments are trying to figure out what roles they can play to strengthen the resilience of this vital supply chain. Furthermore, some measures that would meaningfully increase the resilience of semiconductor manufacturing might conflict with measures that would promote technological competitiveness or national security vis-à-vis China. In this section, we provide an overview of what China is doing to better map, understand and manage this value chain and why Europe needs to invest in its own analytical capabilities for assessment and management.

What China is doing

Chinese official policies for the semiconductor sector, including the reported priorities of China's national-level strategic investment fund for this industry, stress the importance of a whole-value-chain approach.[68] Tangible support measures such as tax incentives and loan facilitation are targeted at multiple production steps (chip design, manufacturing equipment, front-end fabrication and others), reflecting a focus on boosting the capabilities and hence resilience of the whole value chain in China.[69] Conversely, the impact of the semiconductor sector on other industries is watched by Chinese authorities, as reflected in the action taken by China's national market regulator described below.

The extent of visibility that Chinese authorities have of activity in China's semiconductor industry is unclear. However, China has set up senior-level national bureaucratic steering groups to guide the development of this sector and strategic investment funds at national and provincial levels that deal exclusively with the semiconductor sector and have links to government agencies.[70] This suggests that Chinese authorities have institutional channels through which to monitor and receive detailed information across China's semiconductor industry, and through which to compel provision of information or other cooperative action from companies when this is seen to be necessary.

China's wider legal and institutional framework provides authorities with tools for increasing their visibility of industry activity and compelling cooperation from private entities, including foreign actors. For example, China's 2021 Data Security Law allows authorities to obtain data "as necessary to safeguard national security," in accordance with relevant regulations. China's counter-sanctions law provides for extraterritorial jurisdiction and reciprocal punitive measures against foreign entities regarding actions that injure Chinese interests (whether public or private), including compliance with foreign government measures that are perceived to discriminate against Chinese entities.[71]

Visibility of the value chain supports Chinese authorities' proactive stance toward supply constraints in the global semiconductor sector and its effects on other industries in China. For example, in August 2021, China's market regulator established special teams to investigate price-gouging behavior in the market for automotive semiconductors, responding to price monitoring and reporting clues.[72] The investigation results were publicized, and fines up to 1 million RMB (370,000 EUR) were issued to offending firms.[73] Chinese fabrication firms were also reportedly instructed to prioritize domestic customers over foreign ones during the nationwide power supply constraints imposed by Chinese authorities in late 2021, with potential negative implications for transnational supply chain resilience.[74]

Sub-national governments in China are involving themselves intimately in the management of the semiconductor industry: for example, by working with enterprises to identify key suppliers, factor bottlenecks, information deficiencies and other development constraints.[75] Such "supply chain mapping" goes with the promotion of enterprise partnerships along the whole length of the value chain (including in some cases, the appointment of individual firms to lead the implementation of guidance from the authorities) and the development of "integrated innovation ecologies uniting industry, academia and research."[76] The goal is technological upgrading and achieving breakthroughs in key bottlenecks for local industry.

How much such involvement by government authorities helps rather than hinders business activity, and how much is coordinated between jurisdictions around China, is unclear. However, it suggests that Chinese authorities will have an increasingly comprehensive understanding of the local semiconductor industry within their jurisdiction and how it will be impacted by specific developments, such as imposition of export controls by foreign governments or business activity by foreign firms.

How this affects Europe's competitiveness and security

As we argued in the June report, the transnational nature of the semiconductor value chain means that its overall resilience depends on the existing international division of labor. Interdependencies with China are not just an existing fact but can also support transnational resilience by adding global industry capacity, as described below.

However, policy makers must also recognize that there are different types of interdependencies, and that some (especially in the most strategically important technologies) are not in Europe's long-term interests.[77] The challenge is to find a balance between mitigating negative consequences from growing dependence in some fields on China's semiconductor ecosystem and simultaneously strengthening the resilience of the semiconductor value chain as an interdependent transnational whole. This mixed approach aligns with the EU's "Open Strategic Autonomy" concept, with its emphasis on combining the benefits that come from openness with assertive measures to protect European interests and shape the international environment.[78]

This approach will require policy makers to decide about trade-offs between different interests that arise from interdependencies in the semiconductor value chain, as we described in the June report.[79] A measure that strengthens the resilience of the global value chain might negatively impact European member states' national security. For example, increased wafer fabrication capacity within China would make the value chain more resilient in times of skyrocketing demand—as was the case in 2020–2021. At the same time, being dependent on the semiconductor manufacturing capacity of a state described in EU policy as a "systemic rival" comes with various potential national security risks.[80]

To better understand these complex interdependencies, identify chokepoints in the value chain that could be "weaponized" and provide an analytical basis for policymaking, governments around the world and the European Commission have initiated a range of supply chain transparency initiatives.

- In addition to the *100-Day Review*,[81] the U.S. government set up a Supply Chain Disruptions Task Force to address shortages in semiconductors and other supply chains in the short-term.[82] Additionally, there are plans to set up a *Critical Supply Chain Resiliency Program (CSCRP)* at the U.S. Department of Commerce,[83] and the Bureau of Industry and Security (BIS) is supporting these initiatives with requests for information.[84] However, the mixed response from foreign firms and governments to these highly intrusive BIS requests illustrates how resilience is best served by a cooperative international approach, rather than unilateral approaches to visibility and risk mitigation of national dependencies on foreign actors in semiconductors.[85] (The Biden administration has said it could

use the Defense Powers Act to compel further disclosures,[86] and submissions from TSMC and Samsung reportedly omitted detailed client data. The Taiwanese and South Korean governments publicly expressed concern about the negative effects on their companies of disclosing such information.[87])

- As part of a broader partnership announcement, the US and South Korea will "explore the creation of a U.S.-ROK Supply Chain Task Force."[88] Similar to the EU-US Trade and Technology Council, this body will presumably work to reconcile separate preferences on issues relating to the semiconductor value chain—for instance, U.S. opposition to South Korean firm SK Hynix's plans to employ Dutch equipment maker ASML's most advanced technology at its fabrication plant in China, a facility that produces around 15% of the world's supply of DRAM memory chips.[89]

- At the Quad Leaders' Summit, Australia, India, Japan and the US agreed to establish a *Semiconductor Supply Chain Initiative* to map and assess the semiconductor ecosystem, identify vulnerabilities and strengthen resilience.[90] This comes against the backdrop of India's push to establish itself as a hub for global electronics manufacturing, but also of continuing obstacles to this goal that would be more easily resolved through international cooperation.

- A core theme of the newly established *EU-US Trade and Technology Council* is "rebalancing of global supply chains in semiconductors with a view to enhancing respective security of supply."[91]

Governments are trying to figure out what roles they can play to strengthen the resilience of the semiconductor value chain, which predominantly consists of private companies and is characterized by a transnational division of labor.

What Europe should do

Europe, like its democratic partners, faces two challenges when it comes to the resilience of the transnational value chain. First, what role can European governments play in strengthening the resilience of the value chain? Second, in which areas does collaborating with China to strengthen resilience have to be balanced against national security and technology competitiveness risks?

Taking the US as a point of comparison, the Biden administration has decided that "government has a unique ability to solve coordination challenges and serve as a trusted source of data" within the semiconductor value chain, especially when the supply chain is disrupted and shortages occur.[92]

Based on experience with critical infrastructure and cybersecurity regulation, it will most likely take many years, if not a decade, for governments to identify effective and efficient ways for involvement in the semiconductor value chain and how best to strengthen it. To address the various challenges described above, Europe should focus on raising policy makers' visibility of the whole value chain. Priority should also be given to coordinating with governments of non-EU countries whose firms are important actors in the value chain over meaningful strategies for government involvement in this issue.

- **Substantially expand the EU Observatory of Critical Technologies at the Joint Research Center.** One-time assessments[93] and ad-hoc task forces are not adequate policy tools for continuously mapping and assessing such a complex and fast-moving global value chain. The *EU Observatory of Critical Technologies*[94] has the potential to provide a sound analytical base for policy makers to balance national security risks against increased supply chain resilience when cooperating with China. Considerable expertise exists in member states' export control units that the *Observatory of Critical Technologies* should closely collaborate with. To be of most use to policy makers, the Observatory should have dedicated teams of experts for each critical technology, provide regular reports on the health of the global semiconductor value chain and map technological developments that might impact European member states' security.

- **Establish a supply chain resilience working group within the European Alliance on Processors and Semiconductor Technologies.** In collaborating with the Alliance on supply chain resilience issues, the European Commission has the opportunity to work with industry on questions such as information sharing.[95] Thus far, it is unclear what the right type, level of detail and frequency of information sharing between the chip industry and governments is. The U.S. BIS request for comments described above received resistance from industry and foreign governments because it was asking for highly detailed confidential business information.[96] Together with the Alliance, the European Commission could develop a process for information sharing to be able to continuously assess the health of the supply chain.

- **Leverage the EU-US Trade and Technology Council (TTC) to establish best practices for information sharing.** *Working Group 3—Secure Supply Chains* within the TTC has a dedicated track on semiconductors. In addition to its planned activities[97] the working group should also facilitate exchange between both governments on best practices for information sharing with the semiconductor industry. This forum should be used to anticipate U.S. measures targeting China's semiconductor sector, such as the current legislative proposal to screen outbound U.S. investments in critical technology sectors, beyond the current

scope of U.S. export controls or the investment review agency CFIUS.[98] The forum could also work with U.S. policy makers to ensure that European interests are protected and that the partnership is "balanced and of equal interest to both sides"—what the TTC's first joint statement in October declared to be the basis for trans-Atlantic cooperation on this issue.[99]

- **Join or establish like-minded partnerships to cooperate on value chain resilience.** As the semiconductor value chain will continue to be defined by transnational division of labor and high geographic concentration of certain production steps, collaboration with like-minded governments to increase resilience will be critical. Europe could join some of the described initiatives or forge its own bi- and multilateral partnerships with countries such as Japan, Malaysia, Singapore or South Korea. Taiwan's critical role in the semiconductor value chain also makes it an important party to engage, particularly as the US steps up engagement with Taipei on this issue.[100] This will create political challenges vis-a-vis Beijing that will require astute management.

4. Conclusion

The European Commission has defined China as a "negotiating partner," "economic competitor" and "systemic rival." These three aspects of relations with China should inform Europe's approach to strategic policy for semiconductors—a foundational technology for the accelerating digitalization of society and of international economic relations. When envisioning how best to strengthen the resilience of the transnational semiconductor value chain, partnering with China's growing semiconductor ecosystem can be a viable option for some areas but must be weighed against risks.

In some fields, such as assembly, test and packaging, much global capacity is located in China and is increasingly owned by Chinese firms. This has benefits from the viewpoint of transnational resilience, but also raises national security issues described above, and potentially advantages China in international competition to continue improving semiconductor performance. In other areas, such as chip design, it is clear that Europe is at a competitive disadvantage relative to China and must critically assess potential future dependence on a systemic rival. Our previous report published in June 2021, *Mapping China's Semiconductor Ecosystem in the Global Context,* made clear that China has the ambition to become a much more capable, though not self-sufficient, actor in the value chain.[101]

Europe needs to invest in its semiconductor ecosystem not simply because of competition with China but also to ensure that in the future Europe has the capacity to develop and shape technology to address various social objectives. European policy makers have a host of tools at hand to positively influence and strengthen this industry. However, to date, policy debates about the IPCEI Microelectronics and the forthcoming EU Chips Act have mainly resolved around subsidizing front-end manufacturing. This focus is insufficient, and Europe should broaden its scope to address capabilities in other value chain steps where Europe currently lacks capacity—notably chip design and packaging.

International forums such as the EU-US Trade and Technology Council (TTC) should be used to identify areas of meaningful cooperation with partner governments, whether this includes China or involves alignment against China where necessary. The dominant role in the semiconductor value chain of Taiwan, South Korea and Japan, and these economies' close integration with that of China, means they will likely be indispensable partners in a long-term strategic approach to this industry.

Most importantly, European authorities must maintain their focus on the semiconductor value chain beyond the immediate issues of responding to the global chip shortage, passing the EU Chips Act and establishing a *modus vivendi* with the US in

the TTC. European authorities should continue to map, monitor and raise their visibility of this critical value chain to provide an analytical basis for long-term measures to support and develop European capabilities. China has consistently supported its semiconductor industry over decades, adjusting its approach as required, which over time has helped Chinese industry to significantly improve its capabilities and gain influential market share in some fields. Upgrading Europe's semiconductor ecosystem and regaining advantageous positions in the value chain will require a sustained and well-informed approach from policy makers.

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