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Contents

Provide a brief overview of the key components of the semiconductor supply chain and their geographic distribution.

To better understand the global semiconductor value chain, one should understand the different ***production steps (including the supplier markets)***, the ***business models,*** and the different ***types of semiconductors***.

PROCESS STEPS AND SUPPLIER MARKETS

The ***first production step*** in semiconductor manufacturing is ***chip design***. It is the step with the highest value add (50%)[1] and mainly depends on ***electronic design automation (EDA) tool vendors*** and ***third-party IP vendors*** as critical ***supplier markets***. Chip design is not done in isolation but is always based on a particular manufacturing process; it is highly skill and R&D intensive. EDA tools play a crucial role in developing, verifying, and simulating a new chip design on a specific manufacturing technology. Third-party IP is used heavily for standardized functionality such as USB or Bluetooth connectivity that can simply be implemented in a new design, saving development time. Increasingly, companies today develop (but do not necessarily manufacture) their own chips—from automotive OEMs to cloud providers and smartphone manufacturers. U.S. companies are not only leading substantially in chip design for many types of semiconductors, but also the largest (by revenue) EDA tool vendors and IP vendors are ***based in the US***.[2] ***China***'s chip design ecosystem and capabilities are also quickly increasing, mainly due to China's strength in smartphones and consumer electronics.[3]

The ***second production step***, after chip design, is ***wafer fabrication*** (also called "front-end" manufacturing) done in fabrication plants or "fabs." Today, wafer fabrication depends on around 300 chemicals and more than 50 different types of specialized manufacturing equipment and takes more than 1,000 process steps and more than 12 weeks.[4] Thus, front-end manufacturing is highly capital intensive, with new 3nm fabs costing upward of $20 billion. More than 70% of that is due to high manufacturing equipment costs.[5] That also means that fab owners try to utilize their equipment as efficiently as possible: In March 2019, global fab utilization rates were higher than 80% and have been higher than 95% since December 2020.[6] This cost-driven lack of spare manufacturing capacity explains why the value chain struggles to cope with sudden and strong demand fluctuations. Another important aspect is that front-end manufacturing diversified significantly over the past few decades. Public discourse often distinguishes between "cutting-edge" fabs and "everything else." In fact, front-end manufacturing is highly diversified with different types of chips relying on different process technologies and materials. For example, logic semiconductors, such as processors in laptops and smartphones, rely on ever-smaller manufacturing technology (often called "More Moore Scaling"). In contrast, most analog semiconductors, such as chips to charge the battery of an electric vehicle, to transfer data over 28 GHz radio waves, or to control an electric engine, depend on very different materials (silicon-carbide and gallium-nitride) and manufacturing processes. The important regions for front-end manufacturing are ***Taiwan***, ***South Korea***, ***China,*** and ***Japan***.

The third and ***last production step*** is ***assembly, test, and packaging*** (also called "back-end" manufacturing). During this step, all the individual integrated circuits (etched onto the wafer during front-end processes) are diced from the wafer, tested, and then packaged to protect them from the environment and to be able to solder them into the final product, such as a smartphone. Historically, back-end manufacturing has been much more labor-intensive than front-end manufacturing, with lower profit margins and significantly lower added value. This explains why U.S. and European semiconductor companies quickly out-sourced and off-shored back-end fabs to Asia, mainly ***China***, ***Taiwan,*** and ***Malaysia***. [7] However, the economics of back-end manufacturing are changing due to the rise of "advanced packaging" approaches, such as heterogeneous integration. To further push the performance and energy efficiency of future chips, advanced packaging plays a crucial role, blurring the line between front-end and back-end manufacturing but also potentially increasing the added value and R&D intensity of the last production step.[8]

The three important ***supplier markets*** for semiconductor manufacturing (apart from the EDA tool vendors and third-party IP vendors) are ***equipment, chemical***, and ***wafer suppliers***.

Semiconductor manufacturing equipment (SME) is needed for front-end and back-end manufacturing. Front-end manufacturing relies on more than 50 types of SME, such as etch, deposition, and lithography equipment. "More Moore Scaling" (being able to squeeze evermore transistors onto a square millimeter of wafer) forces equipment manufacturers to constantly innovate to increase precision, control contamination and defects, and closely collaborate with chemical suppliers. Furthermore, SME companies typically specialize in specific types of equipment. For example, ASML (NL), Nikon (JP), and Canon (JP) mainly focus on lithography equipment. Thus, fabs rely on a variety of SME vendors, mainly from the ***US***, ***Japan,*** and ***Europe,*** to equip their fabs.[9] China is investing in domestic SME vendors, such as AMEC, Naura, and SMEE, but they are several generations behind their foreign competitors,[10] especially in lithography and etching equipment.[11]

Specialty and bulk ***chemicals***, as well as (noble) gases, are the second important supplier market for semiconductor manufacturing. Modern process technology relies on the highest purity chemicals that often can be supplied only by a small set of vendors. The chemicals market has also seen considerable consolidation in many areas over the past decade, because only large suppliers can justify the necessary investments in new purification and enrichment plants. Fabs today rely heavily on ***Japanese***, ***U.S.,*** and ***European*** chemical suppliers.[12]

Finally, ***wafers*** are the third important supplier market for semiconductor manufacturing. Most semiconductor manufacturing is based on wafers made of silicon. The silicon wafer market is essentially controlled by five vendors: Shin-Etsu Handotai (JP), SUMCO Corporation (JP), GlobalWafers (TW), Siltronic (DE), and SK Siltron (KR). Together, they control around 90% of the global silicon wafer market ($12.6 billion).[13] The two ***leading Japanese vendors*** control more than half of the market. Other types of wafers for specialty and niche technologies, such as silicon-on-insulator (SOI), silicon-carbide (SiC), and gallium-nitride (GaN), are produced by other vendors and supply chains.

For a comprehensive overview of China's competitiveness in each production step and supplier market, please see endnote 11.

BUSINESS MODELS

Historically, all three productions steps—(1) chip design, (2) wafer fabrication, and (3) assembly, test, and packaging—were carried out within a single company, called an ***integrated device manufacturer (IDM)***. The IDM business model, for different reasons, is still predominant in certain semiconductor areas, such as memory chip vendors (Samsung, Micron, and SK Hynix) and analog semiconductor suppliers (Texas Instruments, Analog Devices, Infineon, etc.).

However, since at least the 1990s, an increasing number of companies have focused on one of the three production steps. ***Fabless*** companies focus on chip design and rely on ***foundries*** for contract chip manufacturing. Fabless and ***system companies*** design only chips and outsource manufacturing. However, system companies, such as Apple, Tesla, and Amazon, do not sell their chips but implement them in their own products and systems. The US has, by far, the largest share of fabless companies, such as AMD, Nvidia, and Qualcomm.

Fabs for contract manufacturing are operated by either ***pure-play foundries***, such as TSMC (TW), UMC (TW), Globalfoundries (US), and SMIC (CN), or IDMs that also offer foundry services in some of their fabs, such as Samsung (KR) and Intel (US) in the future. In 2021, TSMC controlled 53% of the global foundry market by revenue.[14]

IDMs and pure-play foundries might perform only front-end manufacturing and outsource back-end manufacturing to ***outsourced semiconductor assembly and test (OSAT)*** suppliers. The biggest OSAT companies are ASE (TW), Amkor (US) and JCET (CN) and the regions with the most back-end capacity (operated by IDMs, pure-play foundries, or OSATs) are ***Taiwan***, ***China,*** and ***Malaysia***.

Finally, IDMs are increasingly outsourcing front-end manufacturing to pure-play foundries. Most analog semiconductor IDMs, such as Infineon (DE), STMicroelectronics (FR), and NXP (NL), rely on pure-play foundries for front-end manufacturing of some of their logic chips, such as microcontrollers. Another example is Intel, which has relied on TSMC for certain types of chips for more than a decade.[15]

TYPES OF SEMICONDUCTORS

The level of market concentration and dynamics also differ for the various types of chips. The following examples illustrate different levels of concentration.

Three ***memory chip*** suppliers—Samsung (KR), SK Hynix (KR), and Micron (US)—control more than 94% of the global DRAM market, which totaled $96 billion in volume in 2021. DRAM is a standardized product that is traded like a commodity, and the three IDMs rely on economies of scale in a highly volatile market with growth rates ranging from +77% to –37% within two years.[16] As most DRAM manufacturing of Samsung and SK Hynix is in ***South Korea***, the country plays a crucial role in the global supply of memory chips.

European, ***U.S.,*** and ***Japanese*** companies are key suppliers of ***analog semiconductors***. Processors and memory chips are purely digital devices, but analog semiconductors interact with the real world (from sensors to motor controllers or radio frequency chips) and are mostly produced by IDMs. The market for analog semiconductors is highly diversified, with small to medium companies often focusing on chips for very specific applications.

General-purpose processors (x86) for laptops, desktops, and servers are essentially controlled by Intel (US) and AMD (US). *Nvidia* (US) controlled more than 80% of the market for ***artificial intelligence accelerators*** for cloud and data centers in 2020.[17]

In summary, the ***global semiconductor value chain*** is ***transnational***, relies on a ***high division of labor*** among companies and regions, and is defined by ***strong interdependencies*** and ***various chokepoints*** at the level of production steps, suppliers, and types of chips. Most importantly, no region can control all the production steps and necessary supplies for cutting-edge semiconductor manufacturing.

From the United States’ and China’s perspective, what are the relative strengths and the key chokepoints each faces in the semiconductor supply chain?

STRENGTHS OF THE U.S. SEMICONDUCTOR ECOSYSTEM

U.S. companies hold very strong positions in many areas of the global semiconductor value chain. Together with U.S. universities, they are also leading in many areas of semiconductor R&D.[18]

Electronic design automation (EDA): The three US-based EDA tool vendors Cadence, Synopsys, and Siemens EDA (formerly Mentor Graphics) essentially control the EDA market. Access to their chip design tools is indispensable for companies that want to develop (cutting-edge) chips. Although China is trying to invest in its domestic EDA ecosystem,[19] it is unlikely that Chinese EDA suppliers, such as X-Epic and Primarius Technologies, will be viable substitutes for Chinese chip designers any time soon.

Front-end manufacturing equipment: The US has some of the leading equipment vendors for certain process steps, such as etching, deposition, and process control.[20] U.S. equipment vendors Applied Materials, KLA, and Lam Research are among the largest vendors (by revenue) internationally and are crucial suppliers to most fabs.

Fabless and system companies (chip design): The U.S. integrated circuit (IC) fabless industry is more than three times larger by revenue than that of Taiwan and more than seven times larger than that of China.[21] U.S. system companies, such as smartphone suppliers (Apple), automotive manufacturers (Tesla), and hyperscalers (Google and Amazon), have also heavily invested in their own chip design capabilities over the past decade, further strengthening the domestic ecosystem. Because chip design is the production step with the highest value add, U.S. chip design companies (fabless and system companies) have the strongest overall position in the global semiconductor ecosystem.

Analog semiconductors: The largest analog semiconductor suppliers, such as Texas Instruments, Analog Devices, Skyworks Solutions, Maxim, and many more, are also based in the United States.[22]

This list is not exhaustive but is meant to show that beyond individual companies, the US has a very strong presence in chip design (as a process step) and critical supplier markets, such as EDA, IP, and manufacturing equipment.

STRENGTHS OF THE CHINESE SEMICONDUCTOR ECOSYSTEM

Back-end manufacturing: Assembly, test, and packaging is certainly the process step where China has gained the most market share over the past 15 years. China’s three leading OSAT suppliers account for 35% of the global OSAT market.[23] According to some estimates, China and Taiwan together account for roughly 60% of global back-end manufacturing capacity.[24]

Front-end manufacturing (mature nodes): Although there are no cutting-edge fabs (<10nm) in China, mainly due to U.S. export restrictions on certain types of manufacturing equipment, China has substantial manufacturing capacity in mature nodes. ***Figure 1*** shows that China has the highest front-end manufacturing capacity (measured in “wafer starts per month,” wspm) for ≥180nm process technologies, compared to all other countries. For fabs between ≥40nm and <180nm, China has the second highest installed capacity, after Taiwan.

Although fabs with 40nm nodes are not used for anything close to a modern processor, they are crucial for analog and discrete semiconductors as well as microcontrollers. Fab capacity at 40nm, 60nm, 90nm, 130nm, and 180nm has also been identified as the most constrained[25] and unlikely to change in the future.[26] Additionally, China is investing the most in these mature nodes compared to all other countries.[27] It is highly likely that in the future foreign countries will increasingly rely on mature node manufacturing capacity within China.[28] ***Figure 2*** shows the accumulated equipment spending by country: Between Q1 2017 and Q1 2022, manufacturing equipment worth $94 billion was shipped to China (to Chinese and foreign fabs). During that period, more equipment was sold to China than to any other country (2.6 times more than to the US). Importantly, due to the U.S. export restrictions on cutting-edge manufacturing equipment (i.e., EUV scanners), none of the equipment shipped to China is for cutting-edge process nodes, only for anything >10nm. That means that China is building out trailing-edge (>10nm to <40nm) and mature node (≥40nm) capacity significantly more than any other country.

Chip design (hyperscalers, consumer electronics, and mobile): China has a quickly growing chip design ecosystem that is increasingly competitive. Similar to their U.S. counterparts, Chinese hyperscalers such as Alibaba and Tencent are investing in their in-house chip design units.[29] As Huawei is struggling, due to the U.S. export restrictions, other Chinese mobile and consumer electronics companies are becoming stronger. Unisoc, a Chinese fabless company focusing on mobile chipsets, gained substantial market shares in entry-level smartphones and tablets, for example, from Samsung.[30]

In summary, China's semiconductor industry is increasingly successful in all three production steps but struggles in supplier markets (IP, EDA, equipment, chemicals, and wafers). That said, the U.S. Semiconductor Industry Association (SIA) estimates, for example, that Chinese equipment vendors could achieve self-reliance in 40nm process technologies "over the next few years."[31]

What are the key features of the semiconductor supply chain that might make government intervention difficult?

Government intervention within the semiconductor ecosystem is not necessarily difficult, depending on the intended outcome. Some types of interventions are highly effective (if not efficient), such as controlling technology transfer. The following is an overview and brief assessment of the different types of government intervention and their efficacy.

Financial incentives (subsidies, grants, etc.): Government financial incentives play a role in the global semiconductor ecosystem, especially for capital-intensive front-end fabs. Because most of the investment costs are for equipment, subsidies can shift the time until the investment breaks even by more than a year.[32] This is especially relevant in periods of potentially low(er) utilization rates: The lower the utilization rate of a fab, the longer it takes until the fab reaches break even. Government subsidies effectively compensate for lower utilization rates and lower the investment risk.[33]

Restricting technology transfer (export restrictions and investment screening): Export restrictions have been placed on semiconductor manufacturing equipment and chemicals for many decades.[34] Although it is debatable to what extent these measures are effective and efficient to curb the technological development of China's semiconductor industry as a whole,[35] they are certainly disruptive for the targeted Chinese company.[36]

Lack of purchasing power: Although governments accounted for around 30% of semiconductor sales in the 1960s,[37] today government and military together account for just 1% of global semiconductor sales.[38] This lack of purchasing power makes it very hard for governments to intervene meaningfully or set incentives through strategic public procurement. They are simply not an important end-customer industry on a global scale.

Governments do not produce semiconductors; companies do: Governments are not part of the global semiconductor value chain; they do not produce semiconductors themselves and are not important end customers of chips. This is crucial to remember, because ultimately, governments can only create incentives and try to guide the market and value chain in a certain direction. It is up to semiconductor companies, and end-customer industries, to follow. As the semiconductor market is highly cyclical, companies will be more risk-averse during a downturn.

In summary, the efficacy of government intervention in the global semiconductor value chain depends on the type of intervention. However, most importantly, understanding the impact of planned interventions, including second- and third-order effects, is very hard in a value chain that is characterized by transnational division of labor, high market-entry barriers, and strong vendor lock-in effects. For example, the U.S. export restrictions on Chinese companies, such as Huawei and SMIC, led other Chinese semiconductor companies and end-customer industries (which feared they would be next in line for export control measures) to start stock-piling chips, materials, and equipment in early 2020—potentially exacerbating the impact of the global chip shortages.[39]

How have East Asian nation-states been so effective in concentrating supply chains in that region?

It is outside the scope of this testimony to provide a robust and exhaustive analysis of the different reasons why Taiwan, South Korea, Japan, Singapore, China, and Malaysia were able to grow a domestic ecosystem and/or attract semiconductor-related foreign investments. Importantly, all of these countries and their companies deployed relatively different strategies and were successful in different production steps and supplier markets.

Looking at Taiwan and South Korea (the two countries with the most advanced manufacturing technologies and very dominant companies in various areas, such as memory chips, mobile chipsets, contract manufacturing, and advanced packaging), industrial policy and government incentives certainly played a role. However, among policy makers in Europe and the US (and potentially elsewhere), five aspects are often underestimated.

The first is ***smart business decisions by companies***. An example is ***Samsung's*** decision to not only produce memory chips but also develop and manufacture their own chipsets for music players and mobile phones since the late 1990s. The resulting better utilization of Samsung's fabs created a competitive advantage early on.[40] Another smart business decision was made in 2005, when Samsung decided to offer under-utilized fab capacity as foundry services to external customers.[41] Today, Samsung is the second largest foundry by revenue.

Another example is ***TSMC*** in Taiwan. TSMC was the first pure-play foundry; they invented the business model. The selling point of any pure-play foundry is that they do not design their own chips and thus, are not in competition with their customers. This is very different from the foundry services offered by IDMs, such as Samsung or (in the future) Intel. Fabless companies must collaborate very closely with foundries to best develop future chip designs on a particular process node. If you are closely collaborating with a competitor, questions of IP protection and trust quickly arise.[42]

The second is the impact of ***continued currency undervaluation*** of the New Taiwan dollar (NTD) and South Korean won (KRW) against the U.S. dollar.[43] The deliberate currency undervaluation through different government interventions keeps the prices of exported goods and services comparatively low, making them potentially more attractive in the international market. The undervalued NTD makes it cheaper for foreign chip design companies to rely on TSMC, UMC, and many other Taiwanese foundries for contract manufacturing.[44] Some scholars argue that Taiwanese companies benefitted perhaps more from the consistently undervalued NTD over the past few decades than from other industrial policy measures.[45]

The third is the ***strength of ecosystems that grew for more than three decades***. It would be naïve to think that countries such as South Korea and Taiwan became semiconductor hubs solely because of government incentives, and that if those incentives were matched by other (Western) regions, the supply chain would "re-shore." These countries are much more than manufacturing hubs after more than three decades of continued growth. They play a crucial role in global semiconductor R&D[46] and have established talent pipelines and well-functioning bureaucracy in direct support of the semiconductor industry. However, they also benefit substantially from regional cluster effects.[47] These benefits make it highly likely that East Asian countries, especially Taiwan and South Korea, will continue to play critical roles within the global semiconductor ecosystem—beyond mere manufacturing locations—far beyond this decade.

The fourth is ***conscious business decisions by Western chip suppliers and end-customer industries***. Western companies also played a role in shifting the global semiconductor value chain toward East Asia. To control capital expenditures, most Western semiconductor companies have established front-end or back-end fabs over the last two decades in countries such as Malaysia, China, and Singapore. If end-customer industries, such as automotive, mobile, and ICT, are not incentivizing geographic diversification through strategic procurement decisions (being willing to pay more), not much will change.

The fifth is that ***the chip shortages are not a result of overdependence on East Asia***. Since 2020, the global semiconductor value chain has been struggling with multiple shortages occurring concurrently in different production steps and supplier markets for different reasons. For some of these constraints, the semiconductor industry itself is to blame, but a large share of supply disruptions stems from poor purchasing and management decisions in end-customer industries.[48] More manufacturing capacity in the US would not have alleviated the shortages in the automotive industry, as one example. To say that "current dependencies on Asia created the chip shortages" is simply not true.[49]

What is "resilience" with respect to the semiconductor supply chain? How much re-shoring, near-shoring, and ally-shoring is feasible in your view? How much is about leveraging strategic interdependence, or the complex interdependencies across the global value chain, to manage vulnerabilities?

When developing long-term industrial and trade policy addressing challenges in a transnational, complex value chain, such as semiconductors, being clear about and distinguishing between long-term policy goals is essential. If one agrees that autarky in semiconductors is neither feasible nor desirable, then policy intervention and long-term initiatives should be assessed in terms of three areas. They can then be prioritized, and conflicting goals identified.

THREE AREAS FOR ASSESSING SEMICONDUCTOR POLICY

For a more comprehensive discussion of the three areas and how they can inform policy decisions vis-à-vis China's semiconductor strategy, please see endnote 11.

***National security*.** As a foundational technology, chips are a prerequisite for today's weapon systems, and governments have an interest in ensuring supply security and strengthening the military's capability to access and develop this technology. Another aspect is denying an adversary access to technology with military utility (controlling technology transfer).

***Global supply chain resilience*.** As every sector depends on access to chips, and the value chain will continue to be transnational, policy measures should also aim to strengthen global supply chain resilience. Are there single points of failure? How quickly can the global supply chain recover from external shocks, such as natural disasters?

***Technological competitiveness*.** The semiconductor ecosystem is highly competitive and innovates with first-mover advantages and a "winner-takes-all" market.[50] Industrial policy can also aim to strengthen the domestic ecosystem to gain a competitive advantage and be able in the long term to continue to innovate and develop new technologies.

Policy makers can assess initiatives that focus on particular *production steps*, *supplier markets,* or *types of semiconductors* through the lens of the three areas. The following are examples.

Example 1 – Back-end manufacturing. Around 60% of the global back-end manufacturing capacity is in China and Taiwan. At the same time, compromising a chip (implementing a hardware backdoor or "kill switch") during back-end processes is more feasible than during front-end manufacturing processes.[51] Thus, relying on Chinese back-end capacity comes with potential risks.

- From the ***national security*** standpoint, near- or ally-shored back-end fabs are preferable to back-end fabs located in China. Substantially re-shoring back-end capacity to the US most likely will not be economically viable due to the significantly lower profit margins, lower value-add, and higher labor intensity compared to front-end manufacturing.
- The increasing importance of advanced packaging (chiplets,[52] heterogeneous integration) also means that government support for back-end manufacturing would not just stem from national security considerations but also potentially address future ***technological competitiveness***.
- Increasing back-end capacity through near- or ally-shoring would have a limited effect on ***global supply chain resilience***. Although back-end capacity was (and partially still is at the time of writing) constrained and contributes to the chip shortages,[53] this production step is geographically less concentrated than, for example, cutting-edge front-end manufacturing.

Example 2 – Semiconductor-grade chemicals. Semiconductor manufacturing relies on many chemicals that often can be sourced from only a few suppliers due to high purity requirements. The noble gases neon and xenon are mainly sourced from Ukraine and Russia[54] and helium mainly from Russia and Qatar, to name just a few. Although semiconductor companies keep an overstock of these chemicals and gases, a supply disruption can have a direct impact on manufacturing capacity. Would investing in a national (or near-shored) reserve[55] for some of these gases be justified to strengthen supply security?

- There would be no impact on ***national security,*** because a chip cannot be compromised via the chemicals used during manufacturing processes.
- A national gas reserve also would not meaningfully impact the ***technological competitiveness*** of the domestic semiconductor industry.
- Such a reserve would strengthen domestic supply security and ***global supply chain resilience***, especially if governments incentivize industry to organize such a reserve as shared resources with joint investments.

MINIMAL VIABLE COOPERATION AND LEVERAGE

In a value chain characterized by transnational division of labor, securing leverage through interdependencies but also fostering cooperation may be a more sensible approach than striving for autarky or self-reliance. China is highly reliant on US-origin semiconductor technology today, but the Chinese semiconductor ecosystem will certainly continue to grow over the next decade. No matter what the US and its allies do, in the future, Chinese companies will have stronger positions within the global value chain than today. Thus, the policy question is, what is better: a Chinese semiconductor ecosystem that is mostly self-reliant but several generations behind the global cutting-edge or one that continues to rely strongly on Western technology but is competing successfully in some markets?[56]

Today, nobody can make cutting-edge chips without lithography equipment from Europe, photomasks and photoresists from Japan,[57] and etching equipment and software from the US. Then everything comes together in Taiwan or South Korea. Although Chinese companies do not play a strong role in cutting-edge semiconductor manufacturing, they have competitive positions in trailing-edge front-end manufacturing and back-end manufacturing, at the very least. Thus, going forward, U.S. and allied policy makers should focus on ensuring leverage through “minimal viable cooperation.”

Ensuring leverage: Interdependency can support stability. Especially when looking at the global semiconductor ecosystem, a goal of industrial and research policy in the US and allied countries should be to ensure that, in the long term, U.S. and allied companies still control critical positions within the global value chain. This is mainly achieved by “running faster.”[58] Doing so requires industrial and research policy that is also focused on “strengthening strengths” (such as cutting-edge U.S. chip design)[59] instead of indiscriminately providing financial support to anything related to chips and trying to copy what already exists in allied countries.

Minimal viable cooperation: Utilizing that leverage by exploiting chokepoints within the global semiconductor value chain will be possible only if there are interdependencies in the long term. Thus, even with the most restrictive trade policy, people within the US and allied governments should still think about avenues for “minimal viable cooperation” with Chinese companies and the Chinese market.

Assess how difficult it would be for the United States and China to achieve "resilience" given that both will be attempting to create asymmetrical dependencies and vulnerabilities?

The European Union (EU) defined resilience as "the ability not only to withstand and cope with challenges but also to undergo transitions in a sustainable, fair, and democratic manner."[60] With that overarching aspiration, "decoupling" from China would not be the aim of industrial and trade policy for one of the U.S. government's closest allies. It would be challenging, if the U.S. government's understanding of "resilience" is to avoid being dependent on the Chinese semiconductor ecosystem so that even in the long-term the Chinese government cannot exploit their industry's position within the global value chain. It would also be hard to operationalize such a definition of "resilience," as China has dominant positions within the *electronics* value chain, from rare earth metals (raw materials for semiconductor production) to printed circuit board production (the next downstream production step after back-end manufacturing)[61] and final assembly. If policy makers want to meaningfully strategize about how best to strengthen resilience (manage interdependencies, assess chokepoints, ensure leverage, and evaluate cooperation), a narrow view on the semiconductor value chain is ill-advised.

A suggested working definition of resilience in semiconductors for the U.S. and allied governments is "to withstand and cope with challenges that arise from interdependencies with China's semiconductor ecosystem." Those challenges are threefold, as previously stated: national security, global supply chain resilience, and technological competitiveness. Each might require different policy measures.

National security challenges arising from interdependencies with China's semiconductor ecosystem: U.S. and allied governments would need to ensure that their militaries do not depend on Chinese semiconductor manufacturing, as well as utilize export restrictions for technologies with clear military utility.

Global supply chain resilience challenges arising from interdependencies with China's semiconductor ecosystem: U.S. and allied governments would need to ensure that there are very limited single points of failure within the Chinese ecosystem. An example is the severe supply chain disruptions due to China's lock-down of Shanghai as part of their "zero COVID" strategy.[62] Strengthening the supply chain's resilience against these types of disruptions would require the participation of end-customer industries (strategic overstocks, instead of just-in-time delivery) as well as cooperation with allied governments.

Technological competitiveness challenges arising from interdependencies with China's semiconductor ecosystem: China's chip design ecosystem will continue to grow and will become increasingly competitive.[63] This means that, in the future, U.S. companies might increasingly rely on chips designed by Chinese companies. To what extent this poses a threat to U.S. technological competitiveness depends on the sector and type of chip. However, the only meaningful way to address that challenge is through long-term industrial and research policy that incentivizes companies to "run faster." As staying at the global competitive edge in semiconductors takes 18 times more R&D resources today than in the 1970s, this can be accomplished only through collaboration with like-minded partners.[64]

In summary, "resilience" in semiconductors should not be interpreted as essentially decoupling from China. Instead, the overarching policy goal for the U.S. and allied governments should be to "withstand and cope with challenges that arise from interdependencies with China's semiconductor ecosystem." This is achievable in the long term but will require consistent and nuanced policy intervention at three areas: national security, global supply chain resilience, and technological competitiveness. Failing to clearly articulate which of these goals a government intervention is aiming for makes it significantly harder not only to coordinate with allies but also to receive the necessary support from the industry.

What specific tools should the U.S. government leverage to build resilience into semiconductor supply chains?

Build up knowledge. To strengthen resilience, coordinate with allies, and manage risks stemming from interdependencies with China's chip ecosystem, the U.S. and allied governments need a deep and holistic understanding of the global semiconductor value chain. This type of knowledge partially exists in export control and investment screening units within governments. To continuously map the value chain and assess interdependencies and chokepoints, governments require institutionalized resources—units that focus solely on long-term mapping of the semiconductor value chain (and potentially other technology value chains in the future). One-off reports[65] and requests for information[66] are not sustainable and should be used only as a starting point. This does not mean that governments should try to micro-manage the value chain and struggle with companies for business confidential information. Industry associations, market analysts, and the financial sector have a wealth of information that, in the first step, governments could build on to establish a mapping framework (including their own data pipelines) that encompasses trade, financial, and market data, including company competitiveness. This could then be augmented with targeted requests for information from companies to fill gaps. Although supply chain *monitoring*, as currently discussed within the EU–US Trade and Technology Council (TTC), should be the responsibility of semiconductor and end-customer industries, strategic, long-term government *mapping* would support existing policy tools (investment screening, export restrictions, sanctions, and subsidies) and inform potential international partnerships.

Understand the long-term impact of export restrictions on your own industry. If the ultimate goal is to curb the technological advancements of China's semiconductor ecosystem at all costs, it makes sense to exploit the dominance of U.S. (and allied) equipment vendors and EDA vendors through export restrictions. However, this comes with potentially significant downsides. First, the semiconductor industry is highly R&D intensive: Equipment suppliers spend 10–15% of revenue on R&D, and EDA suppliers more than 30%. At the same time, China is currently the most important market for equipment suppliers, accounting for more than 30% of equipment sales. Lost sales due to export restrictions negatively impact future R&D to stay at the cutting-edge. How can we compensate for that? Second, if it is not about complete decoupling, and U.S. and allied equipment and EDA suppliers are supposed to stay—at least to some extent—in the Chinese market, export restrictions (if applied broadly and indiscriminately) could be perceived as a business continuity risk by Chinese customers incentivizing efforts to "de-Americanize" supply chains.[67] Third, broad application of export restrictions also fuels China's efforts to develop local alternatives to alleviate chokepoints in the long term.[68] This is not to say that export restrictions are not a viable tool but potentially to the detriment of the long-term competitiveness of the domestic industry.[69]

Coordinate and collaborate with allies. It is unfortunate if groups within the U.S. government truly believe that the US should "move to making chips in America, not friend-shoring."[70] Making chips without relying on ally-shoring for front-end or back-end manufacturing would not strengthen the United States' resilience or be economically viable. The U.S. government should continue and intensify cooperation with like-minded international partners regarding how best to strengthen the resilience of the global semiconductor value chain and work on a shared understanding of what role governments play within the semiconductor ecosystem. In that regard, exchanges with allied governments (such as within the EU-US TTC,[71] with South Korea as part of the planned "Supply Chain and Commercial Dialogue,"[72] or with Japan on "Basic Principles on Semiconductor Cooperation"[73]) are good starting points.

None of this will work without end-customer industries. Semiconductor companies are suppliers of end-customer industries, such as automotive, consumer electronics, ICT, etc. If efforts to restructure the global semiconductor value chain to increase resilience are mainly based on governments "pushing" in contrast to end-customer industries "pulling," the efforts are destined to fail in the long term. Semiconductor suppliers are more likely to invest in domestic manufacturing capacity if there is a market for it: if their customers ask for chips that were manufactured in an "allied" supply chain and are willing to pay a premium. Thus far, in the US and in the EU, much of the efforts surrounding re-, near-, and ally-shoring come from governments and semiconductor suppliers. This is not sustainable without a much more substantial "pull" from end-customer industries that ultimately would need to pay for it.

The Commission is mandated to make recommendations to Congress. What other policy recommendations would you make based on the topic of your testimony?

This is a marathon, not a sprint. If policy makers, both in the US and Europe, are serious about strengthening the resilience of the global semiconductor ecosystem, it will take much more than a decade of continuous and consistent engagement with the semiconductor industry and end-customer industries to elaborate goals, build trust, and understand industry needs. If companies think that this is simply the current *Zeitgeist,* and policy makers soon move on to other areas, not much will change.

The author would like to thank the U.S.–China Economic and Security Review Commission for the opportunity to testify. He would also like to thank Martin Chorzempa for valuable feedback and Julia Hess and Helena Winiger for their help. You can find SNV's previous analysis of the global semiconductor value chain here: [*https://www.stiftung-nv.de/en/project/geotech/publikationen*](https://www.stiftung-nv.de/en/project/geotech/publikationen)

List of Figures

Figure 1: **Front-end capacity as of December 2020 in million wafers per month [source: IC Insights]**

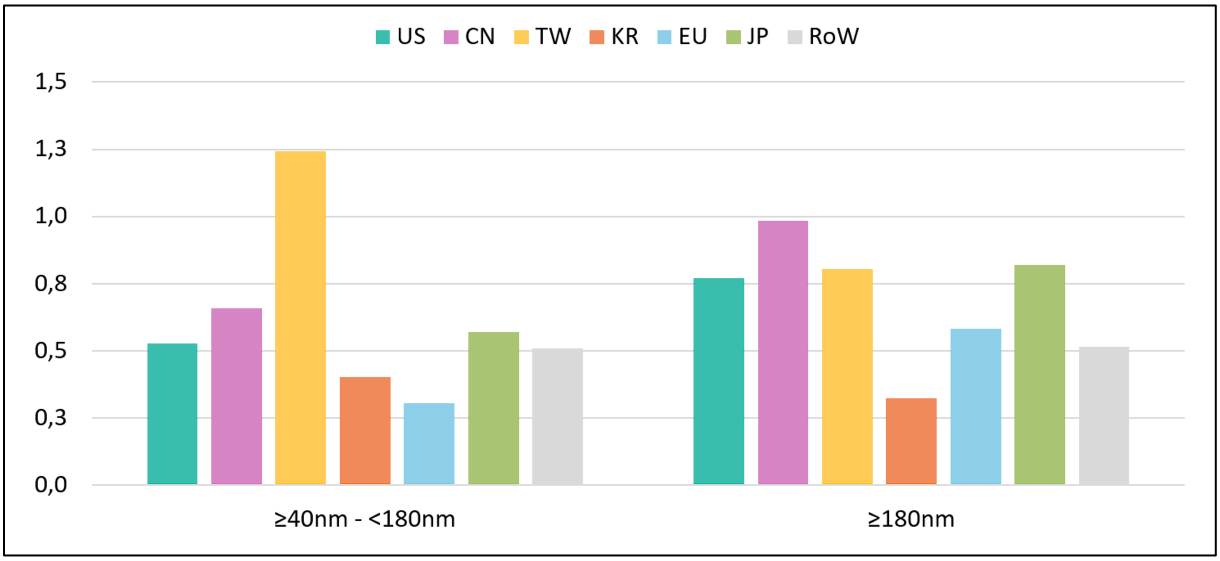
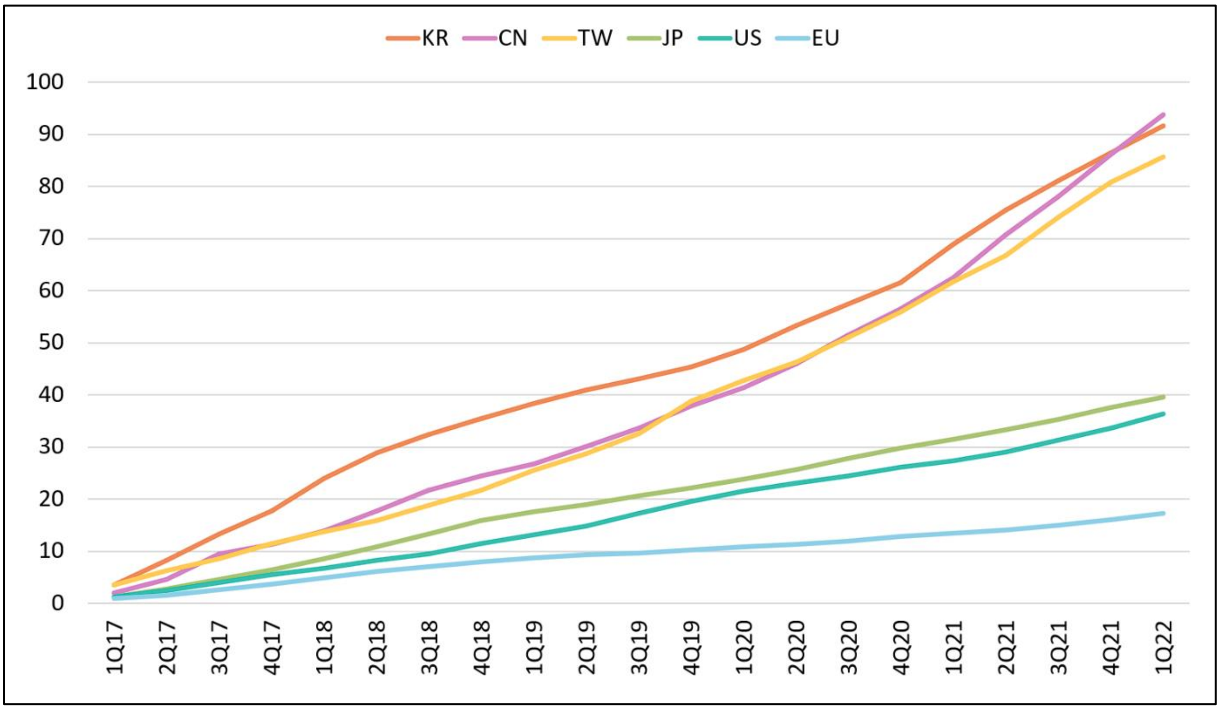


Figure 2: **Accumulated SME spending by destination (country) in USD billion [source: SEMI]**



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