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About the publication:

3 Main Points:

Chips have proven that geography, cutting-edge expertise and power matter in a globalised world. They have been a key ingredient in great power competition and revolutionised warfare, play a key role in the AI revolution, and have a value chain that is global but fraught with weaponised bottlenecks and interdependencies. Yet, in an increasingly competitive international climate, the chip industries' environmental and societal impacts are overlooked.

Highlight Sentence:

"If all others hyper-fixate on maximising certain parameters, the leapfroggers win."

Definition:

Competing with ASML is virtually impossible. To "draw" transistors onto a silicon surface by "writing with light", ASML machines – worth approximately $350 million – operate in extremes.

<u>A Starter's Guide to the "Chip" Industry</u>

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Navigating the semiconductor industry aids our understanding of modern geo-economics, ranging from great power competition to the importance of small details in production that can make or break an innovative edge. Chips, or integrated circuits, are a small piece of semiconductor (usually silicon) containing many interconnected transistors and components. They perform complex functions like processing, memory storage, or signal control in electronics. These chips form the backbone of the world economy, as all modern appliances need them. This starter's guide is drawing an overall picture of the historical significance and current state of the semiconductor value chain, including an annex with technical terms towards the end.

What started in 1956 in California with a company called Shockley Semiconductor Laboratory that produced transistors out of silicon – marking the birthplace of Silicon Valley – would later grow into a global semiconductor industry. The first integrated circuit was built in 1958 by Texas Instruments. From 1968 onwards, Intel initiated the commodification of transistors, betting on standardised hardware (Miller, 2022). Co-founder Gordon Moore's observation that the number of transistors on a microchip doubles approximately every two years, while the cost per transistor decreases, was later coined Moore's Law and declared dead or alive multiple times already (The Economist, 2024b). The entire industry still abides by this imaginative "law".

Great Power Competition

From the very beginning, semiconductors were a central aspect of great power competition. During the Cold War, a network of Soviet spies was set up to acquire cutting-edge US technology. Soviet leader Nikita Khrushchev was obsessed with "catching up and overtaking" the US, determined to fund Zelenograd (Russian for "green city"), a scientific paradise dedicated exclusively to semiconductor production. This so-called "Copy It" strategy, however, failed due to three essential shortcomings: Firstly, tacit (non-codifiable) knowledge made the mere possession of high-tech items insufficient for reproduction, since the Soviets lacked the necessary production know-how, such as specific temperatures, chemical processes, and material purity levels. Secondly, the secretive top-down approach in the Soviet semiconductor sector left little room for creativity, thus hampering innovation. Finally, because the cutting edge was constantly shifting as per Moore's Law, copying last season's US chip designs condemned the USSR to perpetual backwardness (Miller, 2022). Unlike in the industrial era, when the performance of systems slowly stagnated, technology in today's digital era is constantly improving, meaning that a copycat approach is doomed to failure.

Avoiding Soviet mistakes, since 2014, the rising power of China has been pursuing a "fast-follower strategy" that recognises the structural barriers to achieving global technological leadership and the advantages of at least initially focusing on positions with lower value added in the global value chain. Yet rather than striving for an autarkic Chinese semiconductor ecosystem, they are interested in proactively integrating themselves into global technological innovation systems and influencing globalisation dynamics to their advantage (Lee & Kleinhans, 2021). Many, especially Western, firms outsourced production to China, with the latter now dominating and increasingly leveraging their processing capacities. China additionally massively catches up in trailing-edge chip production.

From Missiles to "Hittiles"

Furthermore, semiconductors have revolutionised warfare, allowing for computerised smart guided weapons, first used by the US in the Vietnam War. In 1972, Texas Instruments used silicon transistors to upgrade bombs with a simple laser-guidance system, significantly increasing their accuracy (Miller, 2022). They were even informally called "hittiles" in the military, a play on missiles that are designed to hit their target, distinguished from missiles that are merely designed to explode near their target. While these systems did not bring about US victory, the Pentagon turned guided munitions like Tomahawk missiles into an asset to "offset" the Soviets' overwhelming quantitative military advantage during the Cold War (Miller, 2022).

Why Geography Matters

Moreover, semiconductors have proven again that geography matters, especially for globalised trade. The truly global value chain ranges from the US all the way to Europe, including a heavy burden on East Asia to produce. Most prominently, Taiwan manufactures 90% of the most advanced chips and "has made itself an irreplaceable partner to Silicon Valley" (Miller, 2022, Chapter 12). Faced by the risk of a Chinese invasion or pressuring methods below the threshold of direct conflict, Taiwan had placed its bets on this economic "silicon shield" so far for US protection. Also, the US is interested in a region integrated economically with them:

After their defeat in Vietnam, the US reduced its military presence, but the trans-Pacific supply chains endured, and US Asian allies did not fall like “dominoes to Communism” but were more closely tied to US industries (Miller, 2022, Chapter 12).

On Monopolies and Oligopolies

Seemingly contrary to its global nature, the semiconductor value chain is highly mono- and oligopolised, especially on the leading edge. Like every industry, it started with a few vertically integrated firms. However, the complexity of semiconductor production increased massively, and the industry became too specialised to be economically viable for multiple competitors; yet cooperation remains vital due to mutual dependencies. Since the complexity stagnated, value accrued to distribution networks and integrated firms (Flaningam, 2024). For instance, in the “supplier layer”, ASML from the Netherlands has a monopoly in EUVL (used to “draw” transistors onto silicon) as a Semiconductor Equipment Manufacturer (SME). Some firms like Intel, an Integrated Device Manufacturer (IDM), have vertically integrated chip development, while other “fabless” chip designers like Nvidia have in-house design and rely on foundries like TSMC in Taiwan and on Assembly, Test and Packaging (ATP) companies for manufacturing (Karlsson & Hamrin, 2024).

Consequently, this unimaginable complexity of cutting-edge technology creates extremely high entry barriers. These are determined by economies of scale, capital intensity, government regulations, international politics (e.g., tariffs), intellectual property, high R&D costs, access to resources (e.g., pure silicon), human talent, successful systems integration, and finally tacit and organisational knowledge. Barriers are rather low in chip design, with the US occupying the greatest market share, and barriers are currently highest in the fabrication of leading-edge chips (TSMC) and photolithography equipment (ASML).

The ASML Success Story

Competing with ASML is virtually impossible. To “draw” transistors onto a silicon surface by “writing with light” (The Generalist, 2023), ASML machines – worth approximately $350 million – operate in extremes: To create EUV, tin must be turned into hot plasma by reaching temperatures up to 500,000 degrees, which is hotter than the surface of the sun. Tiny droplets of tin, thin as a human hair, are being blasted with a precision laser in a vacuum, as EUV is highly absorptive. To control the beam of light, perfectly flat mirrors are needed, consisting of 100 layers, each only a few nanometres thick, the “smoothest object ever made”—in Chris Miller’s words (The Generalist, 2023)—which help to focus the light with atomic accuracy onto the silicon wafer. Only one speck of dust ruins the entire batch (The Generalist, 2023). Multiple factors, including scientific luck, beneficial geographic location (Netherlands), right timing, sufficient funding, serendipity in economic circumstances, excelling at supply chain management, determination and strategy, had to align to make ASML’s success possible (Westberg & Hamrin, 2024). ASML’s monopoly solidifies further, as it is currently the only company capable of keeping Moore’s Law alive by printing ever finer transistors.

The ASML success story additionally highlights the significance of systems integration, tacit and organisational knowledge. With 15% of systems produced in-house and 85% by third-party partners – such as mirrors from Zeiss or lasers from Trumpf – ASML must excel at systems integration to make sure all thousands of parts run together smoothly, not interfering with each other (The Generalist, 2023). They engineered their network of business relationships “like a machine”. Also, their culture of innovation fosters continuous development and organisational knowledge building (Westberg & Hamrin, 2024).

The Weaponisation of Interdependencies

In the entire industry, a shift is manifesting from embracing the transnational division of labour to the scrutiny of interdependence since “technological interdependence is increasingly contested, weaponised and fraught with national risk" (Lee & Kleinhans, 2021, p. 2). This is most evident in the ongoing US-China technology rivalry amid global shortages, most severely experienced during the COVID-19 pandemic. Many countries now attribute "strategic importance" to the semiconductor value chain and seek to de-risk vulnerable supply chains. Hence, from a European and US perspective, China emerges as a threat that must be mitigated, due to its increasing economic competitiveness but also potential for civil-military fusion. China most severely lacks R&D and human talent and is pushing its semiconductor ecosystems with protective policies and significant funding. While China's global market shares in chip design, trailing-edge wafer capacity and ATP are multiple times larger than those of Europe, Europe is better positioned concerning chemicals for both front- and back-end process steps. Also, Europe has critical EDA and SME suppliers – effective chokepoints vis-à-vis China that the US government continues to utilise (e.g., no high-end ASML machines for China). Increasing the resilience of cutting-edge wafer fabrication should be most feasible for the US, and Europe could gain ground in the ATP supply chain again. However, Europe must account for major US pressure on China's semiconductor ecosystem and more fierce Chinese responses, a rivalry that "will force semiconductor firms worldwide to at least make an appearance of picking national sides" (Lee & Kleinhans, 2021, p. 20).

The Fate of Moore's Law in the AI Revolution

Ultimately, Moore's Law has kept the entire industry in a state of "paranoid optimism", both bound by it and afraid of its end. In the AI revolution, chipmakers need new ideas to maintain exponential gains in performance "as chips get denser", "AI models get bigger", and "energy use is soaring" (The Economist, 2024a). From rethinking silicon over tighter integration between hardware and software to better packaging, innovative chip design and ditching digital processing altogether, even "the end of Moore's Law will not slow the pace of change" (The Economist, 2024a). Another shift is visible from generalised computing with specialised software to chip specialisation for specific software and hardware-software integration (The Economist, 2024a).

Conclusion: Only the Paranoid Survive

Meanwhile, other experts argue that the AI race is not about chips but rather the availability of electricity (Yoon, 2025). Moreover, environmental and societal implications of the AI race are warned against by scientists and civil society organisations, since the “infrastructure behind AI consumes vast resources – especially energy, but also water and raw materials such as rare earths” (Gröger, 2025, p. 5). Also, reports on immediate impact are piling up, for instance, in areas neighbouring data centres with water shortages or even pollution (Fleury & Jimenez, 2025), let alone broader societal impacts caused by climate change and unequal access and dominance of the chip and AI industries. Who will benefit and profit, and who will drink – quite literally – the polluted water?

Semiconductors have proven that geography, expertise and power matter in a globalised world: They have been a key ingredient in great power competition from the very start, revolutionised warfare, and have a value chain that is truly global and yet highly monopolised at the same time, creating weaponised bottlenecks and interdependencies, and they play the key role in the AI race. Yet, in an increasingly abrasive competitive international climate, the chip (and AI) industries’ environmental and societal impacts are left behind. So, what happens next?

In terms of high-tech competition, as Andrew Grove put it, “Only the paranoid survive.” New disruptive innovation can be a threat for those whose previous knowledge is not as relevant anymore (e.g., ASML becoming obsolete without photolithography needed). Particularly in the semiconductor industry, it is essential to anticipate change or at least be open to it and not fall victim to psychological and organisational challenges or misjudge strategic decisions. For instance, China has swooped European markets with EVs before. If all others hyper-fixate on maximising certain parameters, the leapfroggers win.

Annex: Technical Terms Glossary

AI	artificial intelligence
ATP	assembly, test & packaging
ASML	Advanced Semiconductor Materials Lithography, a Dutch multinational corporation and Semiconductor company that specializes in the development and manufacturing of photolithography machines which are used to produce integrated circuits
Back-end	later production process steps such as assembly, test & packaging
EDA	electronic design automation
EUV	extreme-ultraviolet
EUVL	extreme-ultraviolet lithography
EV	electric vehicles
Fab	fabrication plant
Fabless	companies with in-house chip design that have no fabrication plant and thus rely on foundries for manufacturing
Foundry	company that does contract chip manufacturing
Front-end	wafer fabrication (process steps before ATP)
Hittile	informal military play on an anti-aircraft or anti-satellite missile that is designed to hit its target, distinguished from a missile that is designed to explode near its target
IC	integrated circuit (also called “chip”)
IDM	integrated device manufacturer
IP	intellectual property
Leapfrogging	in business, sometimes, radical innovations will permit new firms to “leapfrog” (skip ahead) the ancient and dominant firm
Organizational	all the knowledge of business value contained in an organization

knowledge	
R&D	research & development
SME	semiconductor manufacturing equipment
Semiconductor	material with electrical conductivity between that of a conductor and an insulator
Silicon	the chemical element silicon has unique electrical properties that allow it to switch between conducting and insulating states, making it an ideal material (= semiconductor) for integrated circuits
Systems integration	the process of bringing together the component sub-systems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system and do not interfere with each other; a challenge of contemporary production, because of the increasing complexity of cutting-edge technology
Tacit knowledge	knowledge that is difficult to extract or articulate, as opposed to codified knowledge, and is therefore more difficult to convey to others through verbalization or writing
Trailing-edge	technology lacking cutting-edge capabilities, thus easier to make
TSMC	Taiwan Semiconductor Manufacturing Company Limited, a Taiwanese multinational semiconductor contract manufacturing and design company
Vertical integration	a vertically integrated company controls multiple stages of its supply chain, from production to distribution, by taking ownership of or acquiring businesses at different levels of the process

References

Flaningam, E. (2024, July). Posts on Semiconductors. *LinkedIn*.

Fleury, M., & Jimenez, N. (2025, July 10). 'I can't drink the water'—Life next to a US data centre. *BBC*. https://www.bbc.com/news/articles/cy8gy7lv448o

Gröger, J., Behrens, F., Gailhofer, P., & Hilbert, I. (2025). *Environmental Impacts of Artificial Intelligence*. Greenpeace. https://www.oeko.de/fileadmin/oekodoc/Report_KI_ENG.pdf

Karlsson, K., & Hamrin, O. (2024). *Understanding the Semiconductor Value Chain: Key Players & Dynamics*.

Lee, J., & Kleinhans, J.-P. (2021). *Mapping China's semiconductor ecosystem in global context*.

Miller, C. (2022). *Chip war: The fight for the world's most critical technology* (First Scribner hardcover edition). Scribner, an imprint of Simon & Schuster, Inc.

The Economist. (2024a). Putting the silicon back in the valley. *The Economist*, *452*, 3–4. https://www.proquest.com/magazines/putting-silicon-back-valley/docview/3106743616/se-2

The Economist. (2024b). The relentless innovation machine. *The Economist*, *452*, 14. https://www.proquest.com/magazines/relentless-innovation-machine/docview/3106743539/se-2

The Generalist. (2023, July 30). ASML: A Monopoly on Magic. *Semiconductors*.

Westberg, P., & Hamrin, O. (2024). *ASML: Architecting Earth's Most Complex Machines*.

Yoon, J. (2025, November 12). *What if the AI race isn't about chips at all?* Financial Times. https://www.ft.com/content/e4c9ac58-d64e-487a-b06d-e71be47f31c9