The semiconductor supply chain: searching for a balance in the global asset

by Luca Mattei

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Abstract: Semiconductors are becoming an indispensable technology to the global order, both for its civilian and military applications. Today, this technology is almost ubiquitous in every segment of society and enables other key tech revolutions, such as Artificial Intelligence and 6G. Understandably, it is a sector highly disputed by the two major international players: People's Republic of China and the United States. Since the early days of this industry, globalisation and offshoring have been major contributors to its emergence and success: key nodes in this supply chain are spread all over the world, inside different geopolitical spheres of influence. However, this setup also brings risk: some of these production nodes experience bottlenecks that can be exploited by the international players who own them. In this scenario, the semiconductor supply chain is bound to increasingly become a ground of contention by geopolitical actors to assert dominance on the global stage. For this reason, this supply chain may say much not only about the future world order but also about relations between allies and adversaries. Today, the semiconductor industry is essential for several military and civil purposes, therefore, its "shape" (i.e. the choice of suppliers, vendors and customers) and "stability" (i.e. how much this supply chain is solid, even among close allies) are major indicators for future international relationships. As will be illustrated in this paper, the semiconductor industry has always been a highly relevant subject, both military and civilian. But over the years this phenomenon has only increased, to the point that the global society could no longer function as we understand it today without this tiny silicon-based technology. This brings us to two emerging questions: are semiconductors essential to modern society to the point of being classifiable as a matter of national security? Moreover, does the procurement of this technology have the power to reshape the relations of the international chessboard? This paper will try to answer these questions by taking into consideration also the perspective of the semiconductor industry itself, which maintains a leading role in this matter.[1]

[1] This work is part of the 6G4SOCIETY project that has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101139070. This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Today, few industries have the ability to influence global policy decisions like the semiconductor (or chip) industry. Often dubbed as "a key enabling technology,"[2] it was born in the 1960s and pioneered in California's famous Silicon Valley, whose name is a direct reference to one of the basic elements of the chip, the silicon wafer. Eminent figures emerged from this sector, such as Robert Noyce of Fairchild (later among the founders of Intel) and Jack Kilby of Texas Instruments.[3] But there are many more companies that have sprung up and made fortunes in the chip market and by investing in its R&D. At first, this was made possible by strategic partnerships with the U.S. federal government allowing its development, as it was seen by Washington as a way to get the upper hand against the Soviet Union during the Cold War. Thus, integrated circuits from Texas Instruments were used in the Minuteman II intercontinental missile (LGM-30F),[4] while those produced by Fairchild were used in the Apollo space program. But semiconductors are not just a military asset; in fact, today they are present in virtually every segment of our life and are essential for the well-functioning of contemporary society. They are used everywhere: for IoT, 5g, automobiles, data centers, telecommunications, artificial intelligence, but also for all kinds of common household appliances. To sum up, semiconductors are necessary for almost anything that has an electronic component. Therefore, it is not surprising that in 2022 the chip industry's turnover accounted a staggering USD $574.1 billion in chip sales.[5]

It has been a long road since the early successes of the Silicon Valley, but since then the semiconductor industry has only expanded and the computational power of a single chip has also increased dramatically.[6] Gordon Moore, one of Noyce's early collaborators and later CEO of Intel, has made the empirical observation that the number of transistors supported by a chip doubles about

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[2] Robert Casanova, "AI, Auto, Industrial Markets Spurred Rebound in Chip Demand During Second Half of 2023," Semiconductor Industry Association, March 18, 2021, https://www.semiconductors.org/ai-auto-industrial-markets-spurred-rebound-in-chip-demand-during-second-half-of-2023/.

[3] Chris Miller, "Chip War: The Fight for the World's Most Critical Technology," (New York: Scribner, 2022), 30-31.

[4] Charles Phipps, "The Early History of ICs at Texas Instruments: A Personal View", IEEE Annals of the History of Computing, 34, 1 (January 2012), 37 - 47.

[5] Robert Casanova, "AI, Auto, Industrial Markets."

[6] Chris Woodford, "A brief history of computers," January 9, 2016, https://digitaltools.labcd.unipi.it/wp-content/uploads/2019/02/VittoreCasarosa_BriefHistoryComputers.pdf.

every two years while the overall size shrinks (also known as Moore's Law). This has allowed this new market to thrive: prices have decreased while the computational power of chips has increased allowing the creation of new technologies and applications.[7] Through the exploitation of semiconductors, several private actors emerged as dominant in different segments of this technology. It is well known that semiconductors enabled the emergence of mobile telephony, an area where there is currently a strong presence of Qualcomm, MediaTek and Apple;[8] or Artificial Intelligence, a space where the main actor, though not uncontested, is NVIDIA.[9] It thus becomes clear that the semiconductor industry has gained international relevance as access to this technology has become critically important for the sustainability of the national economy and society. "Semiconductors are the key enabling technology that helps promote innovation in a broad range of products across virtually all segments of our economy".[10] Therefore, a shortage of semiconductors can have huge consequences on several supply chains, with devastating cascading effects on companies and society as a whole. This can easily happen because this supply chain has been highly globalised since its inception, even at the specific impulse of private companies that have often opted to relocate some of the manufacturing nodes. This is one of the factors of the success of semiconductors, but it also creates critical risks. For instance, when the chip supply chain was slowed down in 2020 due to anti-Covid-19 measures it led to negative economic impacts, in particular the manufacturing of vehicles in Europe.[11]

The geopolitical strife around semiconductors

The semiconductor industry is one of the most heated areas of competition among the globe's major geopolitical players. Amidst export blockades, outright bans of companies and tariff wars, it is a matter of current dispute between the U.S. and the People's Republic of China. In

[7] Chris Miller, "Chip War."

[8] "Global Smartphone AP (Application Processor) Shipments Market Share: Q3 2022 to Q4 2023," Counterpoint, March 11, 2024, https://www.counterpointresearch.com/insights/global-smartphone-ap-market-share/#.

[9] "Why do NVIDIA's chip dominate the AI market," The Economist, February 27, 2024, https://www.economist.com/the-economist-explains/2024/02/27/why-do-nvidias-chips-dominate-the-ai-market.

[10] Robert Casanova, "AI, Auto, Industrial Markets."

[11] Michael Nienaber, "Germany urges Taiwan to help ease auto chip shortage," Reuters, January 24, 2021, https://www.reuters.com/article/us-taiwan-autos-chips-idUSKBN29T04V/.

particular, the U.S. has sought to protect its advantage in semiconductors, by limiting the sharing of sensitive technology from U.S. tech companies to China. This is a bipartisan stance by the U.S., from May 2019, President Trump signed an Executive Order giving the U.S. Commerce Department the power to impose restrictions on the export of technology to Chinese companies, such as Huawei. But this position was also confirmed by President Biden, who, quoting a group of bipartisan members of the Congress, stated that the PRC "aggressively plans to reorient and dominate the semiconductor supply chain".[12] More recently, in October 2022, the White House enacted a package of restrictions on dual-use semiconductor export toward China, aiming to curb its military modernisation.[13] China has met Washington's challenge by restricting the export of Germanium and Gallium, two very important raw materials for chip manufacturing.[14] In addition, China declared that the memory chips produced by the U.S. tech giant Micron Technology pose a threat to national security, thus banning it from its own infrastructure projects.[15] Therefore, it is safe to say that the situation remains tense between Washington and Beijing: both contenders actively use the semiconductor supply chain to their advantage, exploiting the bottlenecks at their disposal.

The supply chain

The semiconductor supply chain is characterised by several bottlenecks that have been leveraged repeatedly by the U.S. and China. As presented, geopolitical actors can put significant pressure on the adversaries by restricting the access to technology and semiconductors are in themselves "a key enabling technology". This was corroborated by a study commissioned by the European Parliament's ITRE Committee, which identified the chip and batteries as an essential

[12] Joseph Biden, "Remarks by President Biden at a Virtual CEO Summit on Semiconductor and Supply Chain Resilience," The White House, April 12, 2021. https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/04/12/remarks-by-president-biden-at-a-virtual-ceo-summit-on-semiconductor-and-supply-chain-resilience/.

[13] Edward Luce, "The risks of U.S.-China decoupling," Financial Times, February 9, 2024, https://www.ft.com/content/6072fef7-f32d-491a-84b8-c1c25c1f828a.

[14] Christopher Cytera, "Gallium, Germanium, and China — The Minerals Inflaming the Global Chip War," CEPA 8 August, 2023, https://cepa.org/article/china-gallium-and-germanium-the-minerals-inflaming-the-global-chip-war/.

[15] Kim Jaewon, Lauly Li, Cheng Ting-Fang, "China's Micron ban creates chip dilemma for Samsung, SK Hynix," May 22, 2023, https://asia.nikkei.com/Business/Tech/Semiconductors/China-s-Micron-ban-creates-chip-dilemma-for-Samsung-SK-Hynix.

technology for digitalisation and for the environmental policies of the future.This explains why dependence on the international semiconductor supply chain is often seen as a liability.

However, getting rid of this dependence could be difficult in the short and medium run, because this industry relies heavily on globalisation and it is not easy its reshoring as it would require "high capital intensity of the industry [...] large-scale investments [and] highly skilled and specialised workforce".[16] For a better understanding of the previous statement, the following paragraphs will highlight certain key steps in the semiconductor supply chain.

The raw materials

Creating a semiconductor first requires the availability of certain raw materials, such as Germanium and Gallium. China enjoys a "near-monopoly" on the export of these two rare metals. According to the U.S. Geological Survey:"China produces about 98% of the world' Gallium and controls 68% of global refined Germanium production in various countries".[17]

The design

The first chips were quite simple, if compared with the ones of today. They were handcrafted and even designed by hand, but "today they have more than a hundred billion" of transistors; this is not possible anymore. This is where Electronic Design Automation (EDA) tools come in. This is a category of software that helps engineers design and develop "increasingly complex chips".[18] It is an area currently dominated by U.S. champions such as Synopsis, Cadence, and Mentor.[19]

The lithography

Lithography is a rather straightforward technology pioneered by Jay Lathrop, an early researcher at Texas Instruments, but it has evolved dramatically over the decades into a colossal

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[16] Maarten De Vet, Daniel Nigohosyan, Jorge Nùnez Ferrer, Ann-Kristin Gross, Silvia Kuehl and Michael Flickenshild, "Impacts of the COVID-19 on EU industries," Study requested by ITRE Committee, March 2021. 46. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662903/IPOL_STU(2021)662903_EN.pdf

[17] Christopher Cytera, "Gallium, Germanium, and China."

[18] Zeyi Zang, "Inside the software that will become the next battle front in US-China chip war." MIT Technology Review. August 18, 2022. https://www.technologyreview.com/2022/08/18/1058116/eda-software-us-china-chip-war.

[19] Chris Miller, "Chip War," 315.

scientific effort called Extreme Ultraviolet Lithography (EUV). Today, it is a particularly interesting bottleneck in the semiconductor supply chain because it is almost entirely controlled by a Dutch company with close ties to the U.S., ASML. This company produces advanced machinery for ultraviolet lithography: an essential step for obtaining state-of-the-art chips. More in-depth, these machines can rely on "the world's flattest mirrors, one of the most powerful commercial lasers and a burst much hotter than the surface of the sun" and can create patterns on a silicon wafer on the order of a few nanometres.[20] This technology is essential even for creating the chips in our PCs or cell phones, but it is also very expensive: cost estimates for a single EUV lithography machine exceed USD 100 million. It is therefore not surprising that this bottleneck has been exploited by the White House in the trade war against Beijing.[21]

The fabs

The ownership and location of a semiconductor plant (also called fabs) is a critical variable to consider, as the material creation of a chip is an expensive process. In fact, building a single fab can cost USD $20 billion. It becomes more sustainable when economies of scale can be applied and specialised machinery and personnel can be relied upon. This is why the fabless chip business model has been so successful, where companies focus on semiconductor design while leaving chip fabrication to other players. Among fab companies emerged the Taiwanese TSMC, which now dominates the fab industry with 59% of the global market share.[22] Analysts believe that this industry preserves Taiwan from political and military interference from the PRC, as the shutdown of Taiwan's chip industry would also heavily affect mainland China. For this reason, semiconductors have also often been nicknamed "the Silicon Shield" in Taiwan.[23] This is part of a decades-long strategy put in place by Taiwanese political leader Li Kwoh-ting, also known as Taiwan's

[20] Chris Miller, “The chip patterning machines that will shape computing’s next act,” MIT Technology Review. June 23, 2023, https://www.technologyreview.com/2023/06/23/1074321/chip-patterning-machines-shape-future/.

[21] Matthew Eitel, “Export Controls — The Keys to Forging a Transatlantic Tech Shield,” July 20, 2023, https://cepa.org/comprehensive-reports/export-controls-the-keys-to-forging-a-transatlantic-tech-shield/.

[22] Vittorio Carlini, “TSMC, la partita globale della fabbrica dei chip contro il rischio cinese,” IlSole24Ore, February 5, 2024, https://www.ilsole24ore.com/art/tsmc-partita-globale-fabbrica-chip-contro-rischio-cinese-AF5Lx5XC.

[23] Chris Miller, “Chip War,” 163.

"Godfather of Technology," who decided to tie Taiwan's fate to Silicon Valley. This strategy can be summarised as: "Americans who were not interested in defending Taiwan might be willing to defend Texas Instruments".[24] Today, this section of the supply chain is viewed with particular concern by the United States, but also by the European Union who fear that a PRC army incursion into Taiwan could end its access to TSMC facilities.

This is also why these geopolitical actors are trying to decrease the risk of this situation with various initiatives. The U.S. are pushing forward the CHIPS and Science Act, with more than 200 billion in subsidies.[25] On the other side of the Atlantic Ocean, the European Union has enacted the Chips Act regulation, which creates a fund of €42 billion and aims to create a complex infrastructure capable of bolstering the European capacity to produce chips and to create an autonomous European chip industry.[26] With this goal in mind, companies such as INTEL or TSMC have been invited to set up semiconductor fabs in the European zone. In addition, the Chips Act also supports other nodes of the supply chain, such as the chip design phase with the creation of a platform that aims to level the playing field with other international competitors. However, there is scepticism that this effort will create an all-European semiconductor supply chain, but rather support for certain sections of the European industry.[27] In addition, the availability of a local chip industry may be an asset for the strategic independence of the European Union from foreign powers, but also a factor of tension between different EU member states. In February 2022, Intel declared that it was interested in contributing to the European semiconductor supply chain by investing 80 billion Euros over the next decade "from research and development (R&D) to

[24] Chris Miller, "Chip War," 65.

[25] Sujai Shivakumar, Charles Wessner and Thomas Howell, "Guardrails" on CHIPS Act Funding to Restrict Investments in China May Restrict Participation in CHIPS Act Incentives, CSIS 7 November 7, 2023, https://www.csis.org/blogs/perspectives-innovation/guardrails-chips-act-funding-restrict-investments-china-may-restrict .

[26] Luisa Franchina and Tommaso Ruocco, "I Chips Act europeo e USA al confronto: due piani necessari per il futuro," July 19, 2019, https://www.agendadigitale.eu/mercati-digitali/i-chips-act-europeo-e-usa-al-confronto-due-piani-necessari-per-il-futuro.

[27] Chris Miller, "Chip War," 332.

manufacturing to state-of-the art packaging technologies" in Germany, Italy and France.[28] However, until now only the plans in Germany are taking off.[29]

On the same line of reasoning, amidst the tension between Washington and Beijing, semiconductors may be a factor of tension between once close allies. For instance, this could be the case of South Korea, whose Samsung may be tempted to fill the market vacuum left in China by Micron's ban.[30] The EU itself is currently contested between the two contenders, as evidenced by Xi Jingping's request to the European Council President Charles Michel whether the EU would join the restrictions imposed by the United States or not.[31]

Conclusion

The semiconductor supply chain has grown on the wings of globalisation; international actors depend heavily on each other for obtaining this enabling technology. This has been often dubbed as “weaponised interdependence”[32] and is seen as a liability.[33] Therefore, it is not surprising that geopolitical actors are currently enacting different measures to gain the self-sufficiency of their supply chain (e.g. the European Chips Act).

Moreover, the chips themselves enable other technological revolutions (such as that of AI). No wonder, then, that the semiconductor industry is the subject of great interest by major geopolitical players. Being cut off from this supply chain means not only economic stagnation, but also a real issue for the well-functioning of society (since semiconductors are ubiquitous in all segments of society) and national security (since chips also have huge military applications). For all

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[28] INTEL, “Intel Announces Initial Investment of Over €33 Billion for R&D and Manufacturing in EU,” INTEL, March 15, 2022, https://www.intel.com/content/www/us/en/newsroom/news/eu-news-2022-release.html#gs.6zkoaq.

[29] Mark Tyson, “Intel's plan to postpone chip plant in Italy confirmed by the country's Industry Minister,” March 15, 2024, https://www.tomshardware.com/tech-industry/intels-plan-to-postpone-chip-plant-in-italy-confirmed-by-the-countrys-industry-minister.

[30] Kim Jaewon, Lauly Li, Cheng Ting-Fang, “China’s Micron ban.”

[31] Cyril Ip, “China trip by European Council chief shows tilt away from US hard line, but marked lift in ties unlikely, analysts say,” South China Morning Post. November 25, 2022, https://www.scmp.com/news/china/diplomacy/article/3201037/china-trip-european-council-chief-shows-tilt-away-us-hard-line-marked-lift-ties-unlikely-analysts.

[32] Aiden Warren and Adam Bartley, “The Digital Power Paradox: U.S.-China Competition, Semiconductors, and Weaponized Interdependence,” The Digital Global Condition, (June 2023), 157 – 177. https://doi.org/10.1007/978-981-19-9980-2_7.

[33] Christopher Cytera, “Gallium, Germanium, and China.”

these reasons, this supply chain will be subject to increasing attention in the future. It is well conceivable that this industry will keep shaping future relations in the international chessboard. This indicator will have to be cautiously monitored as it will help determine, not only the geopolitical set-up of the future, but also the role of the private technology giants in the international scenario.

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