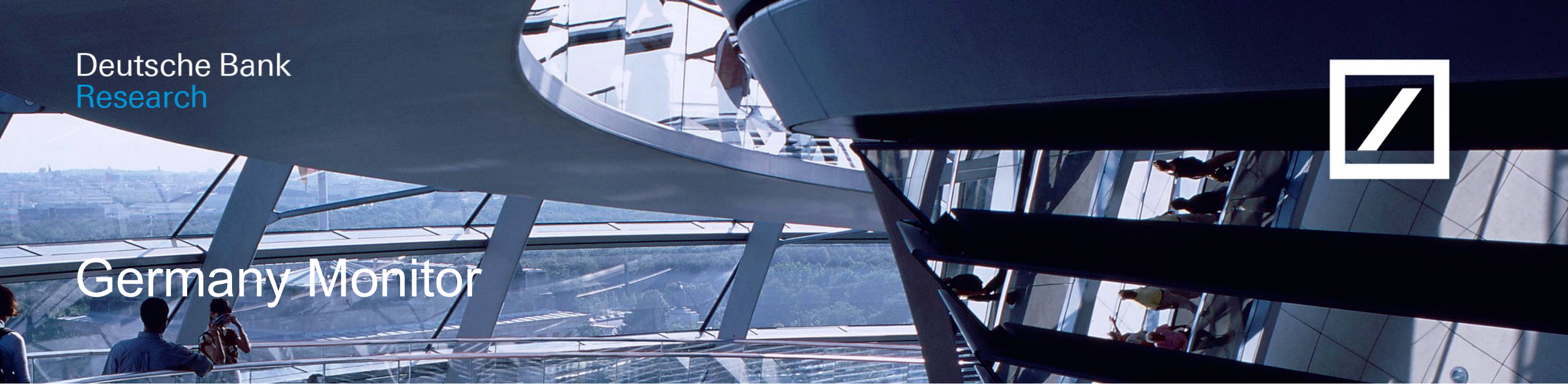

Deutsche Bank
Research

Germany Monitor

Extraordinary semiconductor cycle triggered by one-time events, cyclical and geopolitical effects

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In 2021, global sales in the semiconductor industry reached an all-time high of USD 556 bn. Despite this record figure, the industry currently faces severe challenges.

The present semiconductor cycle is characterized by a triple whammy: Huge demand due to a boost for digitalization, COVID-related and non-COVID related supply shortages and geopolitical tensions.

This has hindered growth in various industries such as computer systems, mobile phones, and automotive, with further cascading effects in related industries.

Due to the sharp rise in chip demand, new chip factories are currently being built in the US, Asia and Europe to meet rising demand over the next decade, boosted by mega trends such as high-performance mobile broadband communication with 5G, the Internet of Things with 6G-enabled edge computing, next generation smartphones, AI and autonomous systems.

COVID has shown the limits of existing supply chains. In addition, geopolitical tensions are leading to a selective reconfiguration of supply chains to reduce vulnerabilities. However, these initiatives will only bear fruit in the long run.

China's "Made in China 2025" policy to build new capabilities in semiconductor research and manufacturing and legislation initiatives (US CHIPS Act and US FABS Act, EU Chips Act) could strengthen continental supply chains and may result in a partial deglobalization. History teaches that high subsidies risk misallocation, which can lead to overcapacity.

When will the present cycle in global chip sales end? While the bottlenecks will drag on for some time, the current cycle could be very long. It might last until the end of 2023. Subsequently, overcapacities and a recession in the semiconductor industry loom. Historically, over the last seven cycles sales contracted sharply by 22% on average from peak to trough. Given the special circumstances, it would not be surprising if sales were to decline by a similar amount or even more.

Contents

1. The current global chip supply chain crisis: Triggers and projections

Since the beginning of the COVID pandemic in early 2020, the economy has been hampered by extraordinary bottlenecks. Supply has been tight for numerous products such as containers, paper, fertilizers and others. However, the shortage of semiconductors, also known as integrated circuits (ICs), has been particularly damaging to the digital economy, manufacturing and the automotive sector. It also had numerous ripple effects on many other industries. The outlook for the duration of the chip shortage is therefore important for many economies as a whole. Global semiconductor revenue grew 26.2% to USD 555.9 bn in 2021. For 2022, sales of USD 601 bn (plus 8.8%) are projected by WSTS, a leading data provider in the sector.

Before the COVID-19 pandemic, global semiconductor supply chains were heavily trimmed for efficiency. Then COVID put them through their paces, and their vulnerability became glaringly obvious. In 2020, working from home boomed, triggering higher demand for computing devices and video conferencing infrastructure. When the global economy was teetering on the precipice, huge fiscal packages were put in place around the world. Government spending was often directed toward structural goals, and climate neutrality, in particular, was high on the agenda. As a result, subsidies were approved to drive digitalization and increase the number of electric vehicles. All these developments strengthened the demand for semiconductors. At the same time, supply was affected by COVID-related lockdowns, staff shortages and production stoppages. For example, Malaysia, a global hub for semiconductor testing and packaging, was severely affected. In addition, lockdowns and congestions at ports lengthened delivery times, and fires at chip factories in Japan and Germany further contributed to supply problems in what can be described as a perfect storm.

Geopolitical tensions have been adding another layer of complexity. The Russian invasion of Ukraine appears to be exacerbating existing shortages. For example, the availability of noble gases from Ukrainian companies is reduced. They are a critically important input for lasers used for photolithography in chip manufacturing. For the most important noble gas, neon, Ukraine has a world market share of about 50%.[1] The Russian invasion of Crimea in 2014 has already led to a dramatic increase in the price of noble gases. Another example is precious metals such as palladium, where 35% of US palladium is sourced from Russian companies.[2] In chip manufacturing, precious metals such as palladium and platinum are extensively used as components of multilayer metallization structures in semiconductors.[3] Another factor is the increasing awareness of China's digital ambitions (NBR 2022) in recent years. The tensions between the US and its allies and China put issues of self-sufficiency and digital sovereignty high on political agendas in various jurisdictions across the globe.

This article looks at the impact of these developments on the global semiconductor supply chain, both from an economic and a technical perspective. Above all, we address the question of whether and when the current supply-demand imbalances will end.

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[1] https://www.reuters.com/technology/exclusive-ukraine-halts-half-worlds-neon-output-chips-clouding-outlook-2022-03-11/

[2] https://www.reuters.com/technology/white-house-tells-chip-industry-brace-russian-supply-disruptions-2022-02-11/

[3] https://www.technology.matthey.com/article/43/1/2-12/

2. Understanding the semiconductor industry

2.1 Key segments of the semiconductor supply chain

The semiconductor supply chain consists of three main production steps:

- Design
- Fabrication
- Assembling, testing, and packaging (ATP)

2.1.1 Designing semiconductors

In chip design, complex software is used to wire and rewire virtually millions of connections on and between chips, sensors and other parts, requiring a deep understanding of electronic components and how they interact. The US is the leading market for semiconductor design. Design services account for roughly one-third of the value added of global semiconductor supply chains. Intellectual property and electronic design automation (EDA) together contribute another 2.5%.[4]

2.1.2 The manufacturing of chips

In terms of value added, manufacturing accounts for about half the value of the global semiconductor industry. It takes place in industry plants called foundries. There, engineering feats are accomplished by creating billions or even trillions of tiny transistors on chips the size of a fingertip. Numerous layers of silicon, lightfast material and metal are applied on thin wafers and later removed by oxidation and laser (lithography). [5] This complex process is carried out in a clean room to avoid contamination. Not only is the foundry an essential part of the global supply chain, but so are the suppliers of manufacturing materials that provide wafers, high-tech lasers for lithography, protective suits for the clean rooms, and so on. As a result, production is very capital intensive, and a modern semiconductor fab regularly costs several billion USD.

The major foundries are located in the high-income countries of East Asia, but also in the US and a few in Europe. In these regions, there is a huge reservoir of well-trained engineers and skilled workers. The global market leader is Taiwan Semiconductor Manufacturing Company (TSMC), which operates the world's largest and most advanced dedicated independent ("pure-play") semiconductor foundry. There, highly innovative extreme ultraviolet lithography (EUV) is used on a large scale. The foundries' suppliers are located all over the world, with some European companies among the market leaders.

2.1.3 The assembling, testing, and packaging

Another important part of the production process is assembling, testing and packaging (commonly abbreviated as ATP). This production step accounts for roughly 10% of the global value added in the industry. In the assembling phase, semiconductors are built into electronic devices. These devices are then extensively tested to sort out defective components. ATP processes are fairly

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[4] Khan et al. (2021). The Semiconductor Supply Chain: Assessing National Competitiveness. CSET Issue Brief.

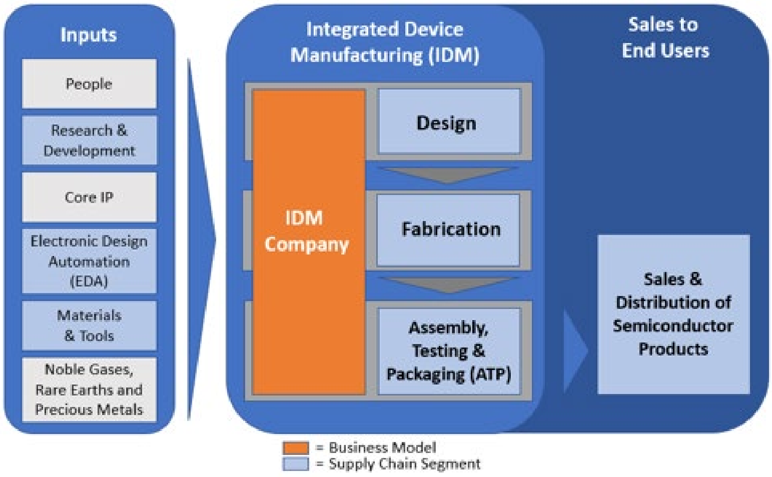
[5] Infineon (2019). Chip Manufacturing – How are Microchips made? YouTube, 17 July 2019.

labor intensive, and many factories are located in low-income countries in the Indo-Pacific region.

2.2 Two dominant business models in semiconductor supply chains

The two business models are the integrated device manufacturer (IDM) model and the fabless foundry model. In the IDM model, one and the same company called IDM performs all three production steps. As a special line of business, so-called IDM foundries offer foundry services in addition to manufacturing their own IC semiconductors. Examples of IDM foundries are Infineon, Intel and Samsung.

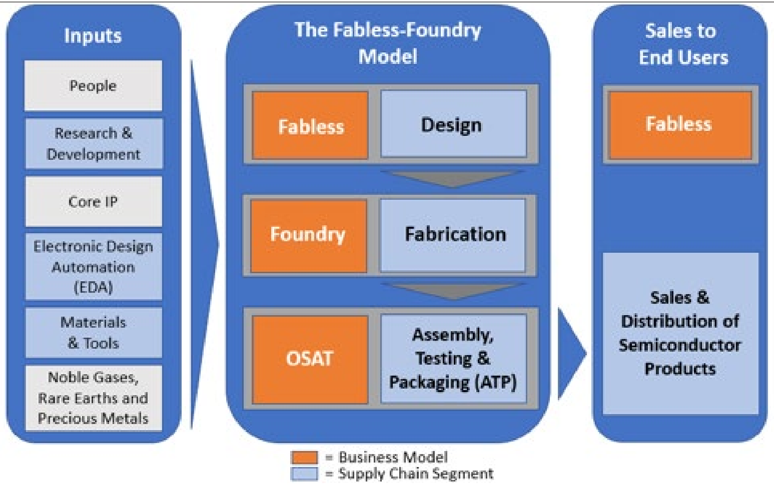
Semiconductor supply chain: The IDM model 1



Source: Deutsche Bank Research

In the fabless-foundry model, each step is performed by different companies. Fabless companies design and sell the chips, but buy manufacturing services from pure-play foundries, as well as assembly, test and packaging services from "outsourced semiconductor assembly and test" (OSAT) companies. A "pure-play" foundry is a company that does not offer a significant volume of IC products of its own design but focuses on manufacturing ICs for other companies. Examples of this are GlobalFoundries and TSMC.

Semiconductor supply chain networks: The Fabless-Foundry-model 2



Source: Deutsche Bank Research

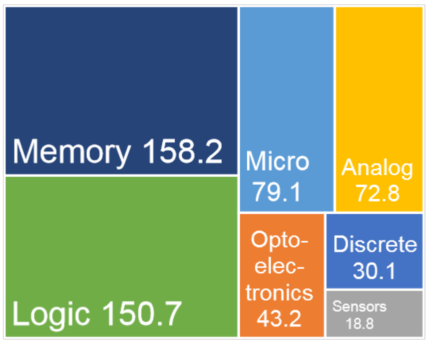
The concept of a global supply chain for semiconductors is based on a comprehensive division of labor originated in a highly influential US government research initiative led by DARPA. This initiative is the so-called “Very Large Scale Integration” (VLSI) project, which began in 1978. One of the objectives was to enable more integrated digital products. In the following decade, semiconductor production was partially shifted to the Indo-Pacific region, resulting in today's sophisticated supply chains.

In 2020, across all business models and supply chains, the US was still the dominant supplier with a market share of over 40%, ahead of South Korea (around 20%). China's market share has increased significantly in recent years and is around 10%. It is likely that it will have already overtaken Japan and Europe in 2021 with a share of almost 10%. Taiwan's share is just under 7%.[6]

2.3 Semiconductors come in many varieties

In this article, we use the terminology of the World Semiconductor Trade Statistics (WSTS)[7] to classify the numerous types of semiconductors. There are some rather simple components such as sensors and optoelectronics. Typically, these are commodities without much added value. Nevertheless, they are indispensable because they represent the interface between the real and the digital world. They measure pressure, motion or light and are especially important for today's smart phones. The first mobile phones had an accelerometer and a proximity sensor. Modern ones, however, are packed with sensors, such as for face unlocking, face recognition, a barometer, a gyroscope, an ambient sight sensor and a magnetometer. Discrete chips are also simple electronic components such as single diodes, resistors, and power transistors that are wired to circuit boards and often handle the current load.

2021 Turnover in the semiconductor industry 3



Sources: Deutsche Bank Research, WSTS

Types of semiconductors 4

Digital and analog integrated circuits		
Digital	Logic	Non-micro high performance integrated circuits with more than 50% of chip area dedicated
	Micro	Microprocessors and microcontrollers with more than 50% of chip area dedicated to digital
	Memory	SRAM, DRAM, (EE)PROM, Flash memory
Analog	Analog	Key function is to process analog signals such as amplifiers, signal converters, interfaces, power management chip
Discretes		Components such as diodes, small transistors, power transistors, thyristors
Optoelectronics		Displays, switches, laser transmitter, image sensors, infrared emitters, light sensors, etc.
Sensors		Temperature sensors, pressure sensors, accelerator, magnetic field sensors, actuators

Sources: WSTS, Deutsche Bank Research

What is often colloquially referred to as a chip is an "integrated circuit" in the WSTS classification. Four types are distinguished: three digital types and one analog type. Analog chips process a real-world analog signal in the integrated circuit or convert a digital output to an analog output signal. Examples include amplifiers and interfaces, such as receivers and line drivers. Microprocessors and microcontrollers for digital logic functions are referred to as Micro. Memory chips store information. Microchips, which perform calculations in microprocessors, i.e., CPUs (central processing units) or microcontrollers; and finally, the most advanced semiconductors, are called logic chips. In terms of

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[6] https://www.semiconductors.org/chinas-share-of-global-chip-sales-now-surpasses-taiwan-closing-in-on-europe-and-japan/

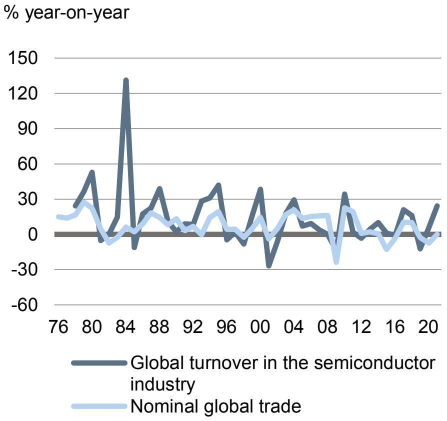
[7] WSTS Product Classification 2022, Issue 1, 05 December 2021.

Chip Size 5

Chip Size	Percentage
> 180 nm	19%
100 - 180 nm	19%
55 - 90 nm	9%
28 - 45 nm	13%
10 - 22 nm	37%
< 10 nm	2%
	100%

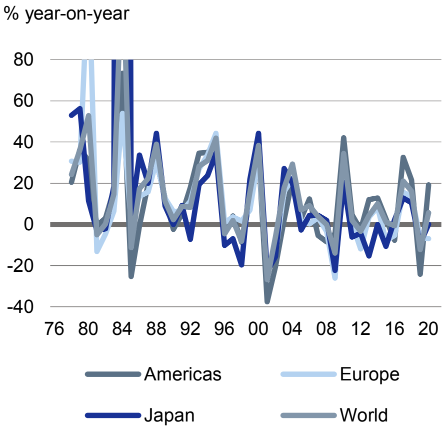
Source: Deutsche Bank Research (based on SEMI data)

1978-2021 Nominal global trade vs. global turnover in the semiconductor industry 6



Sources: Deutsche Bank Research, IMF, SIA

World: Semiconductor turnovers 7



Sources: SIA, Deutsche Bank Research

sales, memory chips account for about 28% and logic chips 27% of total global sales.

Each chip type varies strongly in size and performance. Most transistors produced today have a size between 10 and 22 nanometer (nm). The most modern ones are below 10 nm logic chips which are mainly used in modern computers and mobile phones. Legacy analog and optoelectronic parts which are used in simple electronic circuits have sizes of up to 300 nm. As a recent publication[8] by the U.S. Department of Commerce shows, bottlenecks prevail in standard logic, analog, and optoelectronic chips with a "large" size between 40 and 250 nm, and not in the high-end segment.

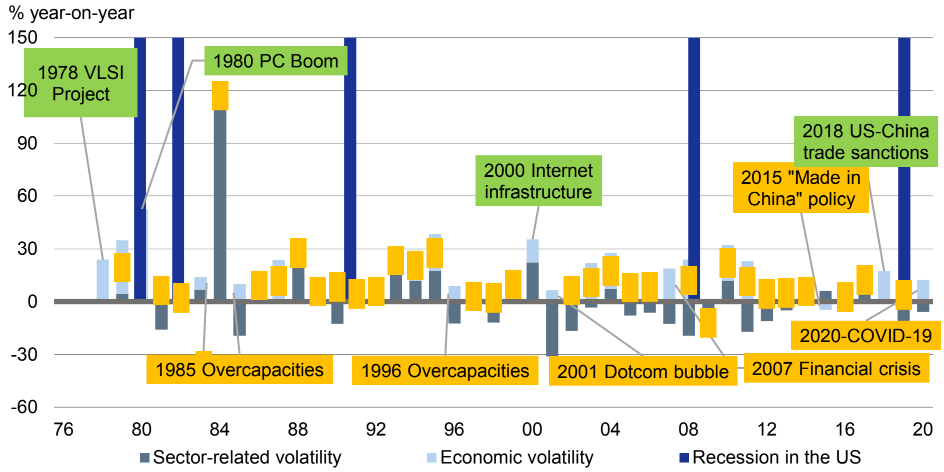
2.4 The semiconductor markets and cyclical changes of revenues

Since its beginnings in the 1960s, the semiconductor industry has become a backbone of the global economy. Today, the market capitalization of the approximately 1,000 listed companies in the sector is about USD 5,000 bn and the global nominal turnover in 2021 was USD 555.9 bn.

From 1977 to 2021, turnover increased by 11% per year on average. This success over the last decades is based on the constant drive to produce cheaper, faster, smaller and less energy-intensive semiconductors. This led to the miniaturization of transistors and constant research into the behavior of materials in the nanoworld. The high level of innovation led to short production life cycles.

Despite exceptional turnover growth, the short cycles led to a decline in sales in about every third year. Several industry-specific characteristics as well as economic factors contribute to this pattern.

Global semiconductor industry: Cyclical changes of revenues 8



Sources: Deutsche Bank Research, IMF, SIA

Firstly, economic factors have a huge impact on the turnover cycle. The industry is very dependent on the economy. Despite the exceptional high growth rates, turnover regularly fell substantially during recessions. Over the last 20 years, turnover in the industry moves also broadly in line with global trade. The correlation between the year-on-year growth rates of nominal global turnover in the sector and nominal global trade across all sectors is 0.65. We use this synchronicity to statistically separate the economy-related from industry-specific

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[8] Results from Request for Information by the US Department of Commerce (2022). https://www.commerce.gov/news/blog/2022/01/results-semiconductor-supply-chain-request-information

effects.[9] The economy-related series accounts for changes in exchange rates, inflation, growth and all other global economic impacts. The residual is defined as sector-specific development. There is also a high degree of synchronization of sales across different regions, which shows how interconnected global supply chains are.

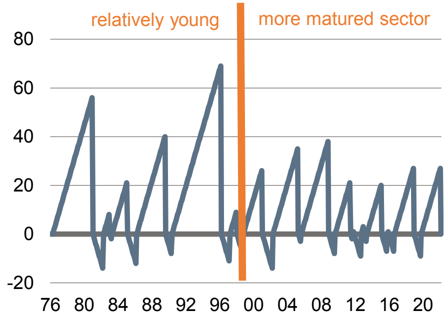
Secondly, clients are used to the steady improvements and have incentives to defer demand before the launch of new chip generations, called nodes. This might be particularly relevant in economic downturns when cost-cutting is more important than in booms.

Thirdly, supply also contributes to the regular contraction in turnover. Huge investments are necessary to launch new nodes. This step-fixed costs needs years to amortize. As a consequence, supply is temporarily inelastic to get boosted subsequently. If demand increases above the planned capacity of a factory, prices and margins will rise and semiconductor firms will start to increase their investments.

Fourthly, the complete process from a raw wafer to integrated circuits often takes several months. This implies long lead times. Hence, production planning in the industry is a challenge. Hardly any company has been operating with large stocks. Often a mix between make-to-order and make-to-stock is applied. But now the pandemic and misjudgements of market developments revealed the shortcomings of this approach. In the first months of 2020, global demand nosedived, and investment plans were put on ice. About the same time, the recovery took off and demand rapidly moved above pre-crisis level and bottlenecks emerged. As a consequence, inventory levels are very low. The US Department of Commerce reports that the median inventory of semiconductor products has dropped from 40 days in 2019 to less than 5 days in 2021.

Length of global sales cycle 9

in months



Sources: SIA, Deutsche Bank Research

2.5 The length of the semiconductor business cycle

Based on the total monthly sales, we define the length of cycles. We define that a cycle will last if the sales in the current month are higher than in the previous month or higher than the average of the last 12 months. When two cycles follow each other, we combine them into one. Our analysis shows that until the mid-1990s the cycles were quite volatile because the industry was still relatively young. As the industry matured, sales growth was strongly correlated with world trade and the cycle length became less volatile. Therefore, we compare the present cycle with only the last seven cycles to assess its potential duration. The present cycle started in October 2019 and has continued until recently.

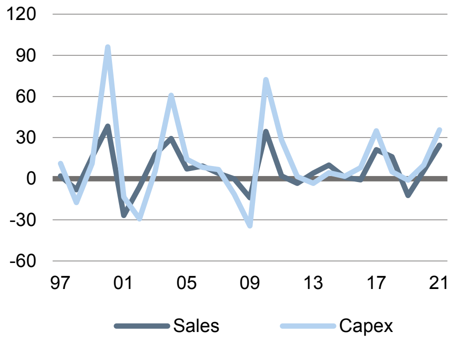
At 29 months, it is already above the historical average of 27.7 months. This already indicates that it is not a normal one. Currently, several atypical factors are creating an extraordinary tailwind:

- Huge structural demand drivers such as digitalization of several industries based on private and public initiatives.
- Stronger-than-normal demand due to COVID-related impulses.
- Supply shortages, both due to COVID effects and the geopolitical tensions.

In our view, all this increases the likelihood that the present cycle will be longer than the longest cycle in the last 25 years, which lasted 38 months between 2005 and 2008.

1997-2021 Sales vs. Capex 10

in % yoy



Sources: Bloomberg Finance LP, Deutsche Bank Research

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[9] We regressed nominal global turnover on nominal global trade. Then, calculated nominal global turnover based on the estimated model and called the result the economy-related whereas the residual is called industry-specific volatility.

Semiconductor business cycles

11

Trough	Peak	Length in months	Sales in %	
			Trough-to-peak	Peak-to-trough
Oct 1998	Dec 2000	26.0	92.7	-46.3
Apr 2002	Mar 2005	35.0	90.0	-5.3
Jul 2005	Oct 2008	38.0	28.3	-39.0
Aug 2009	May 2011	21.0	85.7	-9.2
May 2013	Jan 2015	20.0	29.9	-9.3
Aug 2016	Nov 2018	27.0	62.7	-23.0
	Average	**27.7**	**64.9**	**-22.0**
Oct 2019	until today	27.0	61.8*	

*until Feb 2022

Source: Deutsche Bank Research

2.6 Bullwhip effects weigh on the efficiency of supply chains

In the industry applying make-to-order triggers production volatility downstream, called the bullwhip effect. The semiconductor industry is used to it in normal times. But due to the special circumstances during the pandemic, huge bottlenecks emerged. While supply chains are in general characterized by a collaborative approach based on well-functioning communication between buyers and sellers, the interests of the demand side and the supply side are typically adverse. On the one hand, the desire of engineers for hardware control on the demand side (Lin et al., 2018) leads to ordering in advance to ensure stock availability and, therefore, to avoid production downtimes. On the other hand, semiconductor manufacturers are very sensitive to variations of order levels as huge capex requires a steady flow of revenues. If customer orders fluctuate significantly, feedback loops along the supply chain can lead to forecast deviations, where either overly pessimistic or overly optimistic forecasts can lead to future production bottlenecks or overcapacities.

During the current chip shortage, bullwhip effects were observed primarily in the automotive sector, a major consumer of semiconductors. As consumer demand for cars declined during the first shutdown in 2020 and the number of cars produced nosedived, fewer chips were needed and ordered. As a result, semiconductor manufacturers focused on other end-user industries, mainly computers and mobile devices. Later, when the lockdowns were eased and auto sales rebounded surprisingly sharply, automakers sought to increase their orders again. Chip manufacturers, however, were quickly running at high capacity and shortages emerged.[10] In particular, standard semiconductors installed in cars, medical devices and broadband were in short supply. These include microcontrollers, legacy logic chips, analog chips and optoelectronics chips. Since these are standard chips with a transistor size of at least 40 nm, customers are competing for the same type of chips. The German industry was particularly hard hit as the difference between production and orders in Germany reached an all-time high in 2021 and is still elevated. By contrast, high-tech chips primarily installed into computers and mobile phones faced significantly less supply shortage.[11]

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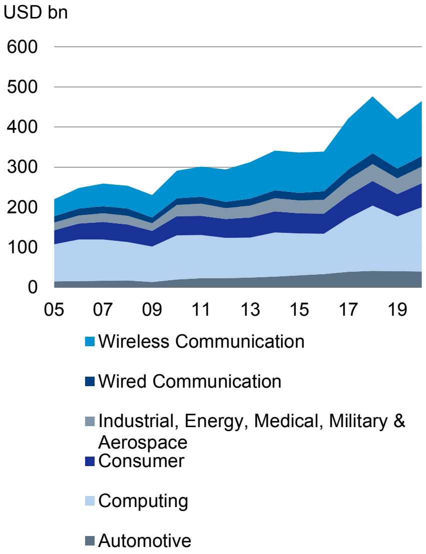
[10] https://www.schroders.com/en/insights/economics/the-three-drivers-of-the-spike-in-demand-for-semiconductors/

[11] https://www.commerce.gov/news/blog/2022/01/results-semiconductor-supply-chain-request-information

2005-2020 Semiconductor turnover by end user

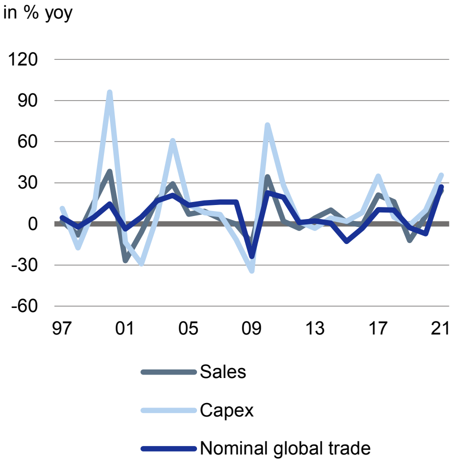
12



Sources: Bloomberg Finance LP, Deutsche Bank Research

1997-2021 Sales vs. Capex

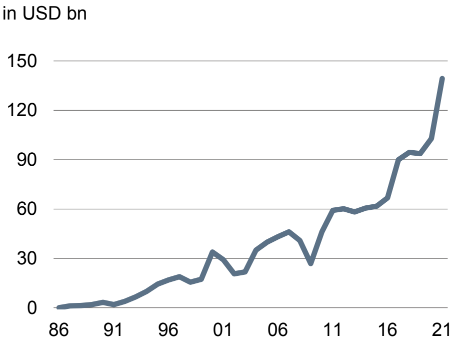
13



Sources: Bloomberg Finance LP, Deutsche Bank Research

Capex spending

14



across 55 large semiconductor companies

Sources: Bloomberg Finance LP, Deutsche Bank Research

2.7 The demand side

Roughly one-third of the semiconductor turnover is generated in the market for computers and mobile phones, respectively. Other important consumer markets are household goods, medical applications, and gaming consoles. However, semiconductors are also built into industrial and military applications.

In 2021, the annual turnover with the automotive industry increased by 26% year-on-year while vehicle production numbers stagnated. This can be explained by both higher prices and higher demand for semiconductors per vehicle. Electric vehicles in their various types and hybrid variants increase the demand for semiconductors. As some car manufacturers focus on high-margin, high-specification vehicles, features such as advanced driver assistance will boost the demand even further.

Demand in other sectors is also expected to increase. In the future, demand for chips for high-performance 5G mobile broadband communications in infrastructures and smartphones is expected to grow significantly. The roll-out of 5G and 6G edge computing will open up new services and business models. This will enable digitalized and fully integrated smart factories, smart homes, smart cities and other smart applications in areas such as digital mobility, digital health and digital energy. The 5G boom, in combination with other technologies such as cloud computing, Big Data and the Internet of Things (IoT), will require huge amounts of chips. In short, a fully digitalized technology-driven world depends on semiconductors as a key technology.

3. The future of global semiconductor production

3.1 Building semiconductor production facilities to meet growing demand

Investment spending in the industry is very cyclical. From 1998 to 2021, the correlation of annual capex and sales is 0.85. So, the short story is that the industry invests more when sales go up. At first sight, smoothing capex spending should reduce volatility and should be profitable, at least in the long run. However, building fabs is very capital intensive. Moreover, the sales-to-capex ratio is structurally on a downward trend. At the end of the 1990s, the ratio was 7, today, it has fallen to below 4. This implies that investment risks are rising. In 2021, the industry invested almost USD 140 bn, an all-time high and a plus of roughly 36% against 2020 and 49% relative to 2019. In 2022, the many announcements over the last months should lift investment spending again close to the 2021 level or even above.

The current investment cycle was triggered by a very high capacity utilization of fabs.[12,13] Normal full global fab capacity utilization is around 80%. Since 2019, the utilization ratio has risen to as high as 95%. Construction of at least 29 fabs with an estimated total production capacity of up to 2.6 million wafers per month has started or will start in 2021 and 2022. This will expand supply by 13% compared to the semiconductor industry's total production capacity of 20.8 million wafers per month in 2020. However, a key bottleneck are equipment and tools for new fabs. It is expected that semiconductor makers will start installing equipment in 2023 since it takes up to two years after ground is broken to reach that phase. So, capacity expansion could even take up to 2024 or beyond. The number of new fabs is likely to climb even further. As we show below, new

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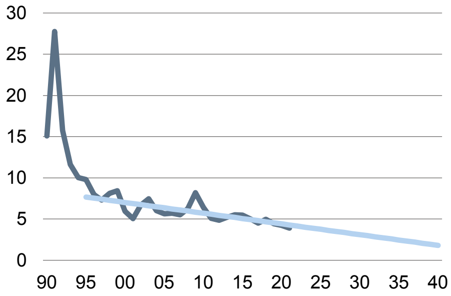
[12] https://www.semiconductors.org/chipmakers-are-ramping-up-production-to-address-semiconductor-shortage-heres-why-that-takes-time/

[13] It defined as the percentage of total available manufacturing capacity being used at any given time, has increased.

Sales-to-capex ratio 15

dimensionless



Sources: Bloomberg Finance LP, Deutsche Bank Research

government initiatives that create incentives for the subsidized development of strategic chip industries in different regions carry the risk of misallocations that lead to overcapacity. The World Fab Forecast report (SEMI 2021) tracks another eight low-probability projects that could start construction in 2022.[14]

New high-volume fabs are built in three world regions 16

Region	Companies and locations	Total
Asia	China: 8 Taiwan: 8 Japan: 2 **Toshiba**: Ishikawa Prefecture **TSMC**: Kumamoto South Korea: 2	20
Americas	USA **Intel**: Arizona, Ohio (two fabs) **TSMC**: Phoenix, Arizona **Samsung**: Austin, Texas **Global Foundries**: New York State	6
Europe	Austria **Infineon Technologies AG**: Villach, Austria Germany **Bosch**: Dresden **TSMC**: Germany (in negotiation with German gov.) **Intel**: Magdeburg (two fabs)	5

Sources: Various press reports, Deutsche Bank Research

3.2 How to make the post-COVID semiconductor supply chain more resilient

There are several measures to compensate for the fragile and volatile nature of semiconductor supply chains. For example, sophisticated forecasting algorithms have been deployed to reduce bullwhip levels with limited success as cyclical effects persist. Another approach is vertical integration to mitigate supply chain risks. The highly complex design and production processes of the semiconductor industry are also kept resilient and highly profitable due to long-term and steady investments in research over several years.

Coopetition is a common practice 17

The semiconductor industry is intensely competitive, but also highly collaborative. Only companies that constantly learn and adapt survive in this industry. Among leading semiconductor companies, technology transfer is a common practice, especially in research collaborations, and also in joint investments. Andrenelli et al. (2019) show for 13 large multinational companies in the semiconductor sector that research collaborations are the predominant form of technology transfer. In the manufacturing sector, licensing, joint ventures, and equity investments are more commonly used than research collaborations.

For example, the Dutch global market leader for lithography ASML has been working with Intel for years to develop cutting-edge production technologies[15]. In 2022, the partners have further expanded their relationship.[16].Similarly, TSMC has technology collaboration partnerships with several suppliers.[17] Likewise, due to the current chip shortage, car manufacturers are intensifying their cooperation with semiconductor companies to avoid bottlenecks in the future.

Source: Deutsche Bank Research

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[14] Decision-making on locations for semiconductor fabs typically focuses on five key factors[14]: available land, infrastructure (power, water, etc.), skilled talent, no natural disasters, and favourable tax incentives. https://www.forbes.com/sites/tiriasresearch/2021/03/23/arizona-becomes-us-semiconductor-central/

[15] https://newsroom.intel.com/news-releases/intel-and-asml-reach-agreements-to-accelerate-key-next-generation-semiconductor-manufacturing-technologies/

[16] https://www.asml.com/en/news/press-releases/2022/intel-and-asml-strengthen-their-collaboration-to-drive-high-na-into-manufacturing-in-2025/

[17] https://pr.tsmc.com/english/news/2898

3.3 A digression: The next generations of semiconductors

3.3.1 Novel 3D chip architectures facilitate even smaller chip size

Today most modern chips produced have a size below 10nm. However, the physical limit of chips in trial production is currently 3 nm. Mass production is expected to begin in 2022. Plenty of research is done to produce even smaller and more powerful chips. Given the physical limitations of atomic structures at a nanoscale level, creating new nodes is very complex. When designing and manufacturing semiconductors in the dimension of nanometers, the interaction between different ultra-thin materials and interference through electromagnetic effects must be taken care of. The solution could be novel three-dimensional (3D) nano-electronic architectures. After several years of research into new materials in the field of nanotechnology, new applications are now being presented, for example:

- IBM has announced[18] its first 2nm chip with improvements in chip performance and energy efficiency. This new milestone is based on a 3D design with vertically stacked transistors on a chip.
- TSMC in collaboration with the National Taiwan University (NTU) and the Massachusetts Institute of Technology (MIT) claims to have successfully researched a 1nm chip.

Although these are important research milestones, it could be several years before the new nodes can be manufactured on an industrial scale.

3.3.2 Search for new materials: Nanoelectronics in the post-silicon era

Another direction for new generations of semiconductors is to replace silicon. The search for new 2-dimensional (2D) materials[19] at atom level such as silicon carbide and a new generation of nano-scale materials (so-called Xenes) as a material to produce semiconductors has already begun. However, feasibility problems such as the high resistance and low current strength of 2D materials still must be overcome. New solutions in the form of carbon nanotubes (CNTs)[20] are currently tested. This could lead to a novel architecture for logic chips with modern 3-D system-on-a-chip designs. This would open another alley for even more powerful semiconductors beyond 2030.

4. Geopolitics reshapes supply chains

Chips are a strategic component of the military, economic and industrial base of superpowers and are therefore "at the center of strong geostrategic interests and at the heart of the global technological race".[21] While offshoring and onshoring of fabs have long been familiar phenomena in the semiconductor industry, the trade dispute between the US and China, which has also turned

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[18] https://newsroom.ibm.com/2021-05-06-IBM-Unveils-Worlds-First-2-Nanometer-Chip-Technology,-Opening-a-New-Frontier-for-Semiconductors

[19] Fiori, Gianluca et al. (2014). Electronics based on two-dimensional materials. NATURE Nanotechnology, Vol. 9, pp. 768-779.

[20] Carbon nanotubes (CNTs) are a quasi-one-dimensional (1D) atomic structure with unique physical and chemical properties. See e.g.: Shanmugam, Nandhinee Radha and Prasad, Shalini (2018). Characteristics of Carbon Nanotubes for Nanoelectronic Device Applications. In: Morris, J.E. (ed.) Nanopackaging. Springer International, Cham. Chapter 18, pp. 597-628. https://doi.org/10.1007/978-3-319-90362-0_18

[21] Blog Post by Thierry Breton (15 September 2021): https://ec.europa.eu/commission/commissioners/2019-2024/breton/blog/how-european-chips-act-will-put-europe-back-tech-race_en

into a tech fight, will most likely have a major impact on the sector. Semiconductor markets are global and are likely to remain so as specialization and international division of labor increase efficiency. However, geopolitical friction has influenced investment decisions in the recent past. In 2017, for example, GlobalFoundries (GF), the world's fourth-largest semiconductor manufacturer, founded in 2009 as a spin-off from AMD, announced a USD 10 bn investment to build a new fab in Chengdu, PRC. In 2018, GF suspended its plans, and in 2019, all installed equipment was cleared out.[22] Recent developments increase the importance of geopolitics. For example,

- Global sanctions against Russia,
- Onshoring, and
- Policies to promote and incentivize regional or national sovereign supply of semiconductors in the U.S., EU, China, and other countries,

are leading to partial reconfiguration of global supply chains and, in some cases, even partial deglobalization.

4.1 Geopolitical tensions, digital sovereignty and planned legislation

4.1.1 The United States

Together, the US and its allied countries and regions enjoy a competitive advantage in virtually every supply chain segment. Before 1984 – in the early days of the chip industry – research and innovation in semiconductor chip development were threatened by "chip piracy", exploiting a critical gap in the law by copying and distributing semiconductor chip products without permission. This legal loophole was filled in the US by the Semiconductor Chip Protection Act of 1984 (or SCPA) and by subsequent similar legislation in Japan, the European Community (EC) and the UK. Given today’s huge supply shortage, there is a renewed discussion about how to strengthen innovation and competitiveness and achieve greater resilience in the event of a disruption in global trade routes.

US semiconductor legislation 18

US CHIPS Act

The Creating Helpful Incentives to Produce Semiconductors for America Act, or CHIPS Act, which is tucked inside the broader competition bill, includes allocation for domestic semiconductor production and incentives to invest in new semiconductor manufacturing facilities in the US.

US FABS Act

The Facilitating American-Built Semiconductors Act (or the FABS Act) was introduced in the US Senate on 17 June 2021[23] and plans to allow a new tax credit for investment in a semiconductor manufacturing facility.

Quelle: Deutsche Bank Research

The US Senate passed the US Innovation and Competitiveness Act in June 2021 that provides subsidies totalling USD 250 bn, of which USD 52 bn is earmarked for the construction of new manufacturing facilities. This legislation, which includes the CHIPS Act, was blocked in the House of Representatives until January 2022, prompting CEOs of semiconductor manufacturers and other industries to write to US Congressional leaders to express their concerns. On 25 January 2022, the US House of Representatives introduced its own bill (the

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[22] https://www.eetimes.com/globalfoundries-abandons-chengdu-wafer-fab/

[23] https://www.congress.gov/bill/117th-congress/senate-bill/2107; https://www.govtrack.us/congress/bills/117/s2107

America Competes Act), in response to the US Senate bill containing USD 45 billion to support supply chain resilience. The bill was passed on 4 February 2022 in the House and on 30 March 2022 in the US Senate.

4.1.2 *The European Union (EU)*

Europe has some strengths. It is a leading center for semiconductor research. European companies also hold a strong position as suppliers of materials and equipment that are needed to run large fabs across the globe. Despite these positives, the EU's share of global semiconductor production has declined from 22% in 1998 to 8% in 2021. In order to respond to this dramatic decline, the EU has outlined a strategy for "Digital Sovereignty".[24] The related legislation of a European Chips Act[25] was announced by the president of the EU, Ursula von der Leyen, in her State of the European Union address on 15 September 2022. If adopted, the Regulation will be directly applicable across the EU. The European CHIPS Act aims to quadruple chip production in the EU-27 by 2030 and covers topics from changing state aid rules to support fabs to taking equity stakes in start-ups.[26] Moreover, the European Commission has identified connected and autonomous vehicles as a strategic cluster because the EU is more dependent on automotive compared to other world regions. In the EU, the auto sector accounts for about 37% of semiconductor demand, according to the European Association of Automotive Suppliers – whereas worldwide it is only 10%.[27]

Of the top 20 global semiconductor companies, three are based in Europe:

- Geneva-based STMicroelectronics was founded in 1987. It also has important subsidiaries in France and Italy.
- Infineon Technologies, founded in 1999 as a spin-off of SIEMENS, is the largest semiconductor manufacturer in Germany.
- NXP Semiconductors was founded in 2006 as a spin-off of Dutch electronics company Philips.

The technology strategies by the US and China pose certain risks for European companies.[28] It is per se an ambitious objective that 20% of the world's microchips should be produced by 2030 in the EU-27. However, the sum of the incentives for the semiconductor industry envisaged by the EU Commission for the period 2021 to 2030 is only a fraction of what China and the US, for example, have promised for the same period.

4.1.3 *PR China*

While China's overall trade surplus surged to a new high of USD 689 bn in 2021, its trade deficit in semiconductors reached USD 233 bn in 2021 up from USD 202.8 bn in 2019. Due to this high dependence on imports, ramping up national production is a key objective.[29] In 2015, China announced its "Made in China 2025" (MIC 2025) policy, a 10-year blueprint for the transformation from a

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[24] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651992/EPRS_BRI(2020)651992_EN.pdf

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0045

[26] https://www.weforum.org/videos/davos-agenda-2022-special-address-by-ursula-von-der-leyen-president-of-the-european-commission-original

[27] https://clepa.eu/mediaroom/automotive-suppliers-highlight-strategic-role-in-eu-semiconductor-policy/

[28] Nardon, Laurence (ed.) (2020). Technology Strategies in China and the United States, and the Challenges for European Companies. Etudes de l'IFRI. Institut français des relations internationales (IFRI), Paris.

[29] https://www.semiconductors.org/chinas-share-of-global-chip-sales-now-surpasses-taiwan-closing-in-on-europe-and-japan/

regional manufacturing giant into a world manufacturing power. This is seen by many analysts as one trigger for the US-China tech dispute. Since then, China is systematically building capabilities and increasing its participation in global chip supply chains at firm level (Sun and Grimes 2016). Over the last years, China has already emerged as an important player in the sector (Grimes and Du, 2020). Its global market share in revenue rose from below 5% in 2017 to presumably above 10% today. Therefore, it has become the third largest producer globally. China's largest semiconductor fabrication company is Shanghai-based SMIC with reported revenues of USD 5.4 bn for 2021. There is also a rush of new firms into the chip industry. In 2020, nearly 15,000 Chinese firms registered as semiconductor enterprises. Many of these are fabless start-ups specializing, for example, in AI computing and other high-end chip designs.

Chinese attempts to reconfigure supply chains in its favor and China's underlying digital ambitions (NBR 2022) have led to concerns in other countries regarding national and international security. The emerging role of China in the global semiconductor value chain (Grimes and Du 2020) is also in line with the policy shift towards the "Dual Circulation Strategy (DCS)" set out by President Xi Jinping in April 2020. Dual Circulation is a metaphor for how China manages its interdependence with the global economy by emphasizing domestic innovation and self-reliance. This has been described as "a robust, state-backed effort to displace the United States from global technology leadership"[30] and is part of the background to the ongoing US-China tech war. The Chinese Communist Party is transforming China and "marching on a new journey of building a modern socialist country in all respects".[31]

4.2 Technical standards and the integrity of standard-setting bodies

Technical standards are critical for innovation, and, in particular, for the future markets of digital services and products. Relevant standards-setting bodies for the digital industry are either private, voluntary organizations such as the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC), or, for example, publicly funded specialized agencies of the United Nations such as the International Telecommunications Union (ITU). Standard-setting takes place in industry-led commissions where the representatives of private large tech companies, technology experts and national standards bodies meet to determine standards used for digital devices and the related infrastructure. Ideally, standards-setting activity should help to maintain true competitiveness and fairness preventing undue control by any single firm or country.

An example of standard-setting are the standards for the next generation of communication systems based on 5G and 6G. These systems will provide high-speed energy efficient massive connectivity for smart phones and IoT devices, all with built-in semiconductors. In order to achieve interoperability between various digital systems and devices, transparent interoperability standards are necessary. Developing such standards and protocols for mobile telecommunications is the aim of the 3rd Generation Partnership Project (3GPP). It is an umbrella initiative of a number of standards organizations from the US, Europe and Asia, who can invite market partners. Founded in 1998, the goal of 3GPP is to create technical specifications that enable mobile devices of all manufacturers to work flawlessly in all communication networks.

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[30] https://www.brookings.edu/testimonies/the-united-states-china-and-the-contest-for-the-fourth-industrial-revolution/

[31] https://www.weforum.org/events/the-davos-agenda-2022/sessions/special-address-by-xi-jinping-president-of-the-peoples-republic-of-china

4.2.1 The EU

In February 2022, the EU Commission presented the EU Strategy on Standardisation[32] on the backdrop that the EU-27 risks falling behind in global standardization organizations with a view of market dominance of US and Chinese tech giants and attempts to rewrite global rules and standards.

4.2.2 The United States

As suggested by the US Chamber of Commerce (2022), the US should seek to reinforce the importance of strong governance practices in international standards setting bodies to advance fair, balanced, industry-led, and consensus-based processes, and prevent distortions.

4.2.3 PR China

As Chinese companies are becoming more and more competitive, with some already have achieved leading market positions, this has created fears that China could export “Made in China” digital business models and solutions to dominate future digital industries.[33] Chinese digital ambitions (NBR 2022) are formulated by Chinese policies, for example, in the area of standardization the official China Standards 2035 process, one of the flagship projects of the Chinese leadership in the coming decade. The risk is that conflicting interests between China and other countries spiral into a tech cold war.[34]

Overall, the integrity of standards-setting bodies is a high public good. Therefore, good-governance mechanisms need to be guaranteed and monitored, and activities of industry participants in standard-setting should be incentivized.

5. Summary and outlook – the present cycle could be very long

5.1 The current shortages are likely to continue for some time

Both demand and supply factors point to ongoing shortages for an extended time period.

Demand for semiconductors remains high, especially in computers, smartphones, and the automotive sector, and could accelerate due to pent-up demand post-COVID. In addition, we expect the rollout of technologies such as 5G broadband smartphones, IoT sensors with 6G edge computing among others. This should pave the way for smart factories, smart homes and autonomous systems. It seems clear that this will result in a full digitalization of our societies and structurally boost for demand.

On the supply side, COVID-19 waves such as the current one in China, in particular in the semiconductor hub Shanghai[35], could repeatedly hamper supply chains. New COVID-19 variants could lead to additional waves of infection in the fall of 2022 and beyond. Another bottleneck is caused by geopolitical tensions

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[32] https://ec.europa.eu/docsroom/documents/48598

[33] https://itif.org/publications/2021/11/08/mapping-international-5g-standards-landscape-and-how-it-impacts-us-strategy

[34] https://dmr.altius.ai/2021/09/18/chinas-standards-2035-project-could-result-in-a-technological-cold-war-the-diplomat/

[35] https://technode.com/2022/04/20/silicon-how-shanghais-semiconductor-industry-is-coping-with-lockdown/

which are likely to reduce the supply of palladium from Russia and neon gas from Ukraine. As a consequence of these developments, today's chip inventories are at a historical low. This points to a very long cycle. This also holds as the capacity build-up will take several years. Fabs under construction will be completed in 2023 or later. Shortages in the supply of materials and equipment for fabs could also delay the completions of fabs. Staff training and the ramp-up of the production processes will also take some time. Due to these constraints, it is very likely that the length of the present cycle will even surpass the very long cycle from July 2005 to Oct 2008 which lasted 38 months. We think, the present cycle may continue at least until the end of 2023. In this case the cycle would be 51 months. Moreover, the current trade tensions between the US and China could spiral into a tech war. Then, the complete disinvestment of GlobalFoundries in China pre-COVID might have been only the start of a further disentanglement between both economies.

5.2 Overcapacities loom in the medium run

Currently, government initiatives in the US, Europe, and other countries in the Indo-Pacific region are loosely coordinated at best and could lead to misallocations that result in overcapacity. These developments could lead to even greater capacity build-up. But even without a tech war, excess capacities are likely**.** We showed that the semiconductor industry strongly depends on the economy. Therefore, if global growth is set to decline in 2023/24 – as proposed by our colleagues –, then demand for semiconductors is likely to decline as well. Overcapacities are a repeated cyclical feature of semiconductor markets. Factors that can potentially lead to overcapacity include both bullwhip effects and subsidies. On average, over the last seven semiconductor cycles since 1998, sales declined by 22% after the peak of the cycle, from peak to trough. Today, we are observing a rather long and very special cycle. It would therefore not be a surprise to see a similar or even greater decline in sales again.

We have also shown that more and more capital expenditures are needed to drive global semiconductor sales. The sales-to-capex ratio has fallen from 7 in the 1990s to less than 4 in 2021. This may indicate that capital spending risks are structurally trending upward. Presumably, new technologies and chip types are needed to reduce the risks again. Beyond 2030, long-term investments in research could bear fruit. New chip architectures and chip designs could further enhance semiconductor performance. In the very long run, the industry could move into a post-silicon era. Moore's Law could therefore remain intact.

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