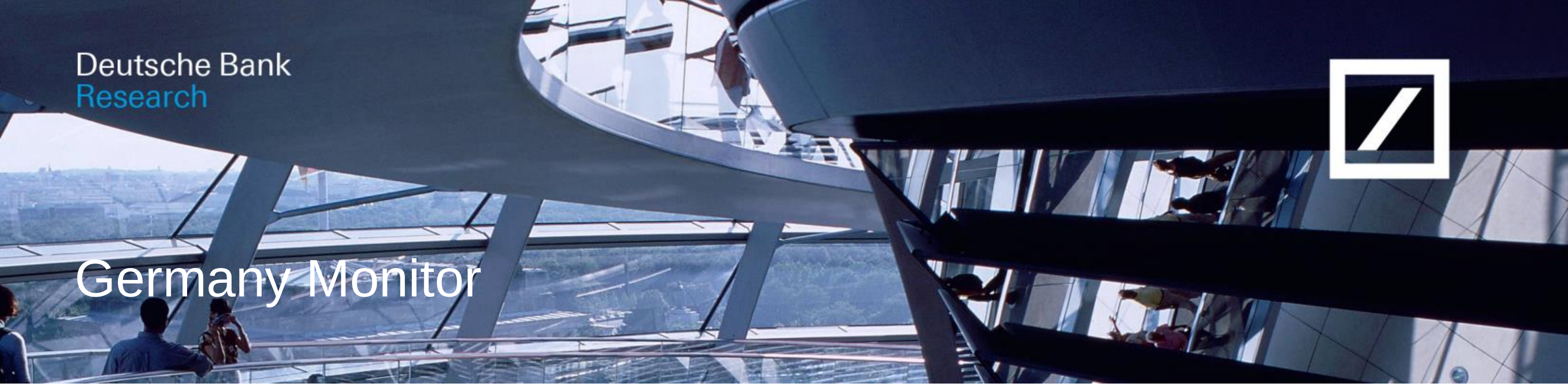

November 1, 2022

3SM: A structural semiconductor sales model

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After a phase of ‘political-legislative calm’, we are entering a new phase of ‘digital sovereignty’ with massive government semiconductor initiatives. An important question is therefore whether subsidies are helpful or will lead to excess supply.

The semiconductor industry is very cyclical. However, in this article we prescind from short-term dynamics and focus on structural (i.e., non-cyclical) trends until 2030.

To project future market developments, we compare demand and supply in our new structural semiconductor sales model (3SM). Based on our previous research, we calculate global capital stock as the basis for future structural supply.

As in the past decades, demand growth for semiconductors should outperform global growth. Due to the ongoing digital transformation of industries and entire societies, demand could easily exceed our projections.

Even without this additional demand boost, we identify a huge structural annual supply shortage of USD 300 bn in 2030. This result is mainly based on an increasing capital intensity of chip production which constrains output and supply.

To completely fill this gap, annual capex must increase from USD 160 bn in 2022 to USD 382 bn by 2030. Such an investment boost may face many restrictions; in particular, a lack of capacities among suppliers, finding enough highly skilled talent, and lead times to build fabs.

Government initiatives could be helpful to address the gap. However, based on the recently announced initiatives worth roughly USD 100 bn, we still think that the supply shortage in 2030 will clearly remain very large.

As the industry may face technological hurdles – which are likely to be the reason for the rising capital intensity – it might be wise to invest more in the development of new (rather than existing) technologies. This would also help to avoid further concentration in the sector.

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Introduction: From 'political-legislative calm' to a 'digital sovereignty' imperative

For decades, the semiconductor industry has been one of the fastest growing sectors against the backdrop of the rise of the digital economy. Today, semiconductors occupy a top position in global trade and are an integral part of the infrastructure in all industries and most products. Both the huge demand for digital goods and services and the constant supply of new and innovative nodes that offer faster, cheaper, and more efficient computing power have contributed to this success.

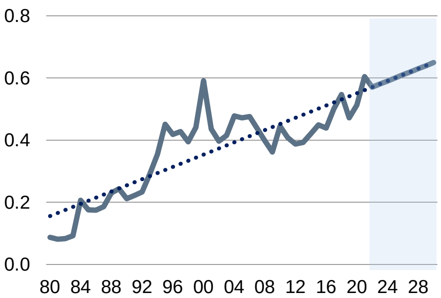
The years between 2008 and 2021 were characterized by a phase of political-legislative calm, mainly a laissez-faire approach with relatively little state intervention in the semiconductor industry. The exemption was China (see details below) with subsidies of approx. USD 50 bn from 2000 to 2020. Now, triggered by geopolitical tensions and growing awareness of the fragility of global supply chains, digital sovereignty has become a political imperative worldwide. A key question is therefore whether industrial policy in the form of higher public R&D spending, tax exemptions and manufacturing grants among others will be helpful.

Our article is structured as follows: First, we focus on the semiconductor market balance over the past decades. We assume that the rising importance of the semiconductor industry for the global economy will continue. Second, we look at the demand side and calculate the existing global per capita sales. Third, we compute the global capital stock and show that the capital intensity is increasing structurally. This is the basis for estimating the future production and sales capacity of the industry. We then apply our structural semiconductor sales model (3SM) to assess the impact of various government initiatives on the future of the semiconductor market. A key finding is that our calculations imply a structural supply shortage through 2030. Our findings show that government initiatives could be helpful, but – with currently known subsidies – can only mitigate the shortage.

Global semiconductor market 2022-2030: Higher revenues ahead

Semiconductors sales relative to global nominal GDP | 1

in % of GDP



Sources: Deutsche Bank Research, IMF, WSTS

Semiconductor sales[1] are very volatile. According to our calculations, the average duration of a boom phase from 1998 to the present is 28.5 months from the trough to the peak. The subsequent downturn from peak to trough lasted 12.5 months on average. Despite this volatility, the industry has been very successful. Annual sales grew by an average of 6.9% (CAGR) during this period. As a consequence, nominal global sales regularly reach new highs, with the current peak in 2021 at USD 582 bn. Today, the semiconductor industry accounts for almost 0.6% of nominal global GDP, which is slightly above the long-term trend (see Chart 1).

In the past, semiconductor sales grew faster than GDP. As a rule of thumb, the ratio increased by almost 0.1 percentage points (pp) per decade. Should this trend continue, the ratio is forecasted to rise to 0.65% in 2030.[2] We calculate that nominal GDP will increase from USD 96 tn in 2021 to USD 150 tn in 2030.

[1] It should be noted that the following data relate only to sales of semiconductors and do not include sales of end products such as computers, cell phones, and other consumer equipment.

[2] Since prices for semiconductors have fallen massively in recent decades, the higher share of semiconductor sales to global nominal GDP implies that the number of chips has overproportionally increased for both industry and consumer products. Moreover, the performance of chips has skyrocketed which implies that our model does not take into account any hedonic price effects.

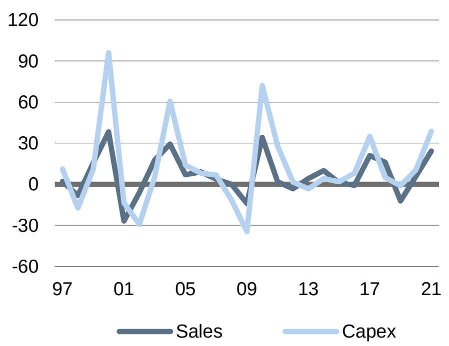
Then, global nominal semiconductor sales would be roughly USD 1,017 bn in 2030.

Semiconductor demand follows historical trend

Demand is highly uneven across the global population. Due to the lack of detailed statistics, we plausibly capture the future surge in demand by decomposing revenue into the number of people and per capita demand. We use the global urban population as a proxy for the number of people with access to digital products and services. The average annual revenue growth of 6.9% from 1998 to 2021 can then be split into global urban population growth, which accounts for 2.2 pp, and per capita revenue growth, which accounts for 4.7 pp. In 2021, the global urban area was populated by about 4.4 bn people. The associated semiconductor revenue was USD 130 per capita. In 2030, the urban population is estimated to have grown to about 5.2 bn people, representing slightly more than 60% of the total global population (2021: 57%). Based on the trend described above, per capita demand will have increased to almost USD 200 per capita in 2030, a substantial plus of more than 50% relative to today. However, this could be a conservative estimate as many production processes in many industries and in many economies will be digitalized. Accordingly, demand could exceed the historical trend.

1997-2021 Sales vs. Capex 2

in % yoy



Sources: Bloomberg Finance LP, Deutsche Bank Research

Brief overview of assumptions for modeling structural semiconductor sales

Demand:

— Demand follows the historical trend of global sales relative to global nominal GDP

Supply:

— Supply is modeled by the ratio of sales to capital stock

— We assess the size of the government initiatives to calculate the impact on future supply

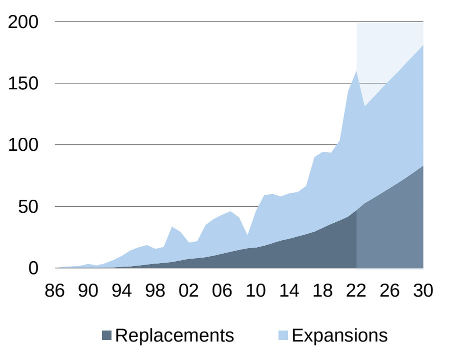
— 2022-2030 Capex follows historical trend

High capital intensity puts the supply side in a bind

The standard production functions in economics take into account labor, capital, and technology. However, because of the very high capital intensity, we focus solely on capital. It seems also likely that capital has been growing very closely in line with technology advancements. For example, process control, photolithography, material removal, cleaning and deposition have made impressive progresses to achieve the miniaturization of chips over the last decades. Modern factories can cost up to USD 20 bn, especially depending on node size (among many other factors). From 1998 to 2021, the constant annual growth rate of capital expenditures was 10%.

1986-2030 Investments 3

USD bn



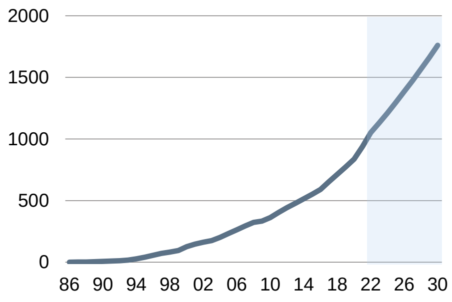
Replacement investments calculated under the assumption of annual depreciation of 5%.

Sources: Bloomberg Finance LP, Deutsche Bank Research

Based on these figures and assuming a depreciation rate of 5%, the global capital stock increased to USD 937 bn in 2021. Another implication is that the replacement investments account for USD 41.8 bn and expansion investments account for USD 101.6 bn in 2021, in total USD 143.4 bn. Given the huge investment needs during the pandemic and a very high capacity utilization at global production sites, a new record in capital spending seems likely. Based on Bloomberg data, we suggest that capital spending will be around USD 160 bn in

1986-2030 Capital stock 4

USD bn

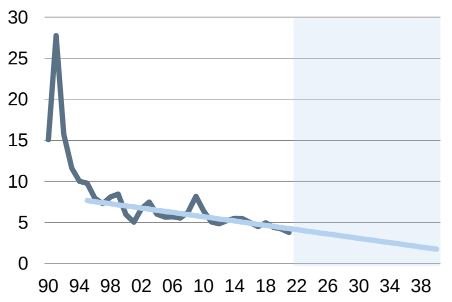


Assuming an annual depreciation rate of 5%.

Sources: Bloomberg Finance LP, Deutsche Bank Research

Sales-to-capex ratio 5

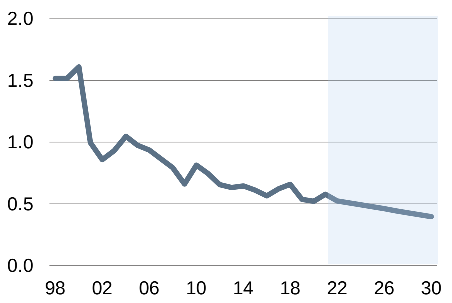
dimensionless



Sources: Bloomberg Finance LP, Deutsche Bank Research

1986-2030 Sales to capital stock 6

Ratio



Assuming an annual depreciation rate of 5%.

Sources: Bloomberg Finance LP, Deutsche Bank Research

2022.[3] This would be a new all-time high, mainly due to the huge capacity utilization during the pandemic, which was well above the historical average of 80%, with some companies still reporting capacity utilization of over 100% in 2022.[4] As a result, global capital stock will increase to USD 1,051 bn in 2022. As global GDP growth is forecast to be subdued and as the semiconductor cycle is expected to end in 2023[5], we assume capex to fall back to its historical trend from 2023 to 2030. This implies a capex of USD 131 bn in 2023 and USD 173 bn in 2030. If this is true, the capital stock will have reached USD 1,760 bn by 2030.[6]

New generations of more innovative chips require more and more capital. Capital intensity has increased across the industry and the sales-to-capital stock ratio has clearly fallen over the last 25 years. As described above, with capex growth of 10% clearly exceeding sales growth of 6.9% on average. This puts pressure on top manufacturers to further optimize their operations of high-volume manufacturing, for example through deploying innovative methods[7], new materials and improved equipment to achieve higher levels of throughput, higher yield per wafer, reliability, and better quality combined with cost-conscious strategies.

Around 20 years ago, the sales-to-capital stock ratio was well above 1, dropping until 2021 to only 0.58. Based on the trend since 2009, we forecast the sales-to-capital stock ratio to fall further to 0.40 by 2030. Based on our capex assumption, global supply will increase from USD 582 bn in 2021 to only USD 699 bn. This represents a huge supply shortage of more than USD 300 bn, as above we calculated that demand is expected to exceed USD 1,000 bn.

An obvious solution would be to extend the capital stock in order to increase supply and to meet demand. A capital stock worth USD 2,563 bn would be necessary such that supply and demand are both worth USD 1,017 bn in 2030. Therefore, capex would have to more than double from USD 160 bn in 2022 to USD 382 bn in 2030[8]. This implies a constant average growth rate of 11.5% per year, even above the already relatively high historical average of roughly 10%. This might also be counterintuitive as mature industries typically lower their growth rates in capex. In addition, such expansion is complicated by potential constraints from equipment suppliers. The fact that high-precision factories take years to develop and build, with many complex challenges. Another issue is the significant skills gap as it is hard to find sufficient talent. As a result, there are only a few companies in the world today that can master these challenges for nodes less than 7 mm. The declining sales-to-capital stock ratio could be interpreted as the economic limits of current production technologies. Even if our calculations are too pessimistic and if we relax assumptions, it seems very difficult to eliminate shortages.

[3] Currently, Bloomberg data imply that capex will be USD 146 bn in 2022. However, we think the calculations will be revised upwards over the course of the year.
[4] SemiWiki (2022). The open forum for semiconductor professionals. [Online] Available at: https://semiwiki.com/
[5] See our article published in May 2022. [Online] Available at: https://www.dbresearch.de/PROD/RPS_DE-PROD/PROD0000000000522983/Extraordinary_semiconductor_cycle_triggered_by_one.PDF
[6] Under the assumption that annual capex remained above USD 160 bn after 2022 and increased slightly from there to over USD 200 bn in 2030, the capital stock would increase to almost USD 2,000 bn, implying an annual supply of USD 796 bn. The structural supply shortage would then be roughly USD 200 bn. We consider this scenario unlikely as equipment suppliers may be unable to ramp up their production capacities as quickly.
[7] For example, improved wafer cleaning has recently emerged as a top engineering challenge.
[8] To the best of our knowledge, this is far above any other estimate in the industry.

Less government support in the past

Given the strategic importance of semiconductors, governments have supported the semiconductor industry since the beginnings of the industry in the 1960s in the US. In the time period from 2014 to 2018, based on OECD data[9], total government support through manufacturing grants exceeded USD 50 bn. Looking at the time span between 2000 and 2020, SIA reports[10] that – based on an analysis of national-level direct funding to companies – manufacturing grants and subsidies totalled more than USD 75 bn, of which China accounted for about USD 50 bn and South Korea, Singapore, and Japan each between USD 5 to 10 bn.

During the last two decades, the subsidies in Europe amounted to only USD 2.5 bn and none in the US. This correlates with a dwindling share of chips manufactured in the US and Europe. In contrast, since 2011 the Chinese government has announced over USD 100 bn in subsidies to its domestic semiconductor industry, with a significant portion dedicated not only to chip manufacturing, but also assembly and testing. This figure also includes a number of measures such as public procurement with favorable purchase contracts or support for location decisions, for example, through industrial parks and discounted land.

Today, various government initiatives have already become law or are in the planning stage. However, some of the investment figures should be viewed with a certain degree of caution, as many details have not yet been determined or published. First, the US CHIPS and Science Act, which was signed into law on 9 August 2022, provides roughly USD 280 bn in new funding for research and domestic manufacturing of semiconductors in the US. According to the Biden Administration[11], this includes USD 39 bn in direct manufacturing incentives. Additionally, a 25% investment tax credit for capital expenses for manufacturing of semiconductors and related equipment is included. Secondly, the subsidies of the EU Chips Act are planned to be EUR 11 bn plus another EUR 2 bn through a new EU Chips Fund. In addition to EU funding, there will be co-funding by EU member countries. Thirdly, a range of other countries, in particular in Asia, plan government initiatives. The total global subsidies which go into capex could amount to around USD 100 bn until 2030, in our view.

Based on the sales-to-capital stock ratio for 2021 of 0.58, the additional capital through subsidies of USD 100 bn would increase sales only slightly by more than USD 58 bn. This annual sales figure would steadily decline with the lower sales-to-capital stock ratio over the coming years. For 2030, the additional sales would decline to only USD 40 bn. To some extent, this estimate could be even an exaggeration if crowding-out effects reduced private investments. A boost of an added USD 40 bn to global supply in 2030 will only very partially close the structural shortage described above. This shows that government initiatives are important not only from a geopolitical perspective. In general, meeting demand might be a struggle in the future. Moreover, the falling sales-to-capex ratio reflects one side of the coin; the other side is that the sector is dominated by a few global companies. This is also underpinned by an increase in the Herfindahl-Hirschman index, especially in the foundry and wafer segments[12]. So

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[9] https://www.oecd-ilibrary.org/docserver/8fe4491d-en.pdf
[10] https://www.semiconductors.org/wp-content/uploads/2020/07/U.S.-Needs-Greater-Semiconductor-Manufacturing-Incentives-Infographic1.pdf
[11] https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/
[12] McKinsey (2022). Strategies for leadership in the semiconductor world. April 2022. [Online] Available at: https://www.mckinsey.com/industries/semiconductors/our-insights/strategies-to-lead-in-the-semiconductor-world/

the high market concentration in the sector might be another issue where government interventions could become necessary.

This challenge could also lead to a paradigm shift towards a strategic semiconductor management[13] by OEMs and suppliers, and whether such a shift will improve the output performance of the industry. Breakthroughs in innovation could increase productivity. Government initiatives are also already helpful to stimulate new technologies. The European Innovation Council (EIC)[14] is already investing in programs to reduce the cost and time of new chip designs. The EIC funding portfolio also includes an accelerator scheme that supports start-ups and SMEs with market creating innovation potential in the semiconductor and quantum technologies sector. Further support for research is arising from the US CHIPS and Science Act and similar programs in Asia.

Results and implications

Based on our structural semiconductor sales model (3SM), global demand for semiconductors will increase. We forecast that demand will exceed USD 1,000 bn in 2030. At the same time, global supply will not be able to keep up with demand. Without further government initiatives we identify a huge structural annual supply shortage of over USD 300 bn in 2030. This finding is mainly based on a very high and rising capital intensity. The technological frontier of chip production is now approaching the 3 nm limit. The underlying technological and operations complexities are rising as ever smaller chip sizes are only possible through enormous investment in new production facilities and equipment. This may imply that the current production technology is reaching economic limits. Our analysis shows that even if we relax our assumptions, it seems plausible that the supply shortage will abate only gradually. The trend toward decreasing cost per semiconductor has already stopped. Given the huge supply shortage it would be no surprise that prices could increase. However, ultimately, there is a limit to what customers are willing to pay for.

Against this backdrop, recent government initiatives such as the US CHIPS Act or the proposed EU Chips Act could be helpful in boosting supply. But even these additional investments are likely to reduce the supply shortage only partially. Under our assumptions, the supply shortage will still be clearly above USD 200 bn in 2030. The high concentration in the market may also send another message. As the current government initiatives may solve the shortage only partially, it may be necessary to foster new technologies. While 450 mm wafer fabs are still in the future, moving from 200 mm to 300 mm fabs and operational-level optimization can lead to more cost effectiveness. Investing in future technologies such as quantum and nanophotonics as well as new materials for the post-silicon era is of key importance. Such measures could help reduce capital intensity and high market concentration and close the structural supply gap, at least in the long term.

Finally, we emphasize the shortcomings of our high-level approach. First, a global supply shortage does not necessarily mean supply bottlenecks for all chip types (logic, analog, memory, optoelectronics, discrete semiconductors, optoelectronics, and sensors) and regions. However, if there are no bottlenecks in one subsector or country, this suggests even greater shortages for the other subsectors. Our model does not distinguish between different trends in capital intensity for leading and lagging semiconductor designs and process technologies. Secondly, geopolitical tensions may lead to a very stringent market segmentation between China and the rest. It might then become

[13] https://www.porsche-consulting.com/de/medien/publikationen/detail/white-paper-strategic-semiconductor-management/
[14] https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_730

necessary to analyze both markets individually. Thirdly, to the best of our knowledge, we are the first to calculate the global capital stock in the semiconductor industry and to use it to calculate structural supply. Therefore, our results are only an initial estimate.

A red flag indicating a change in our model would be a turnaround in the sales-to-capex ratio, i.e. an increase would indicate increased effectiveness of investments in design and production resulting in higher sales, and therefore a better chance to close the structural supply gap.

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We would like to thank our colleagues Ross Seymore, Rob Sanders, and Sidney Ho for their comments to this article.