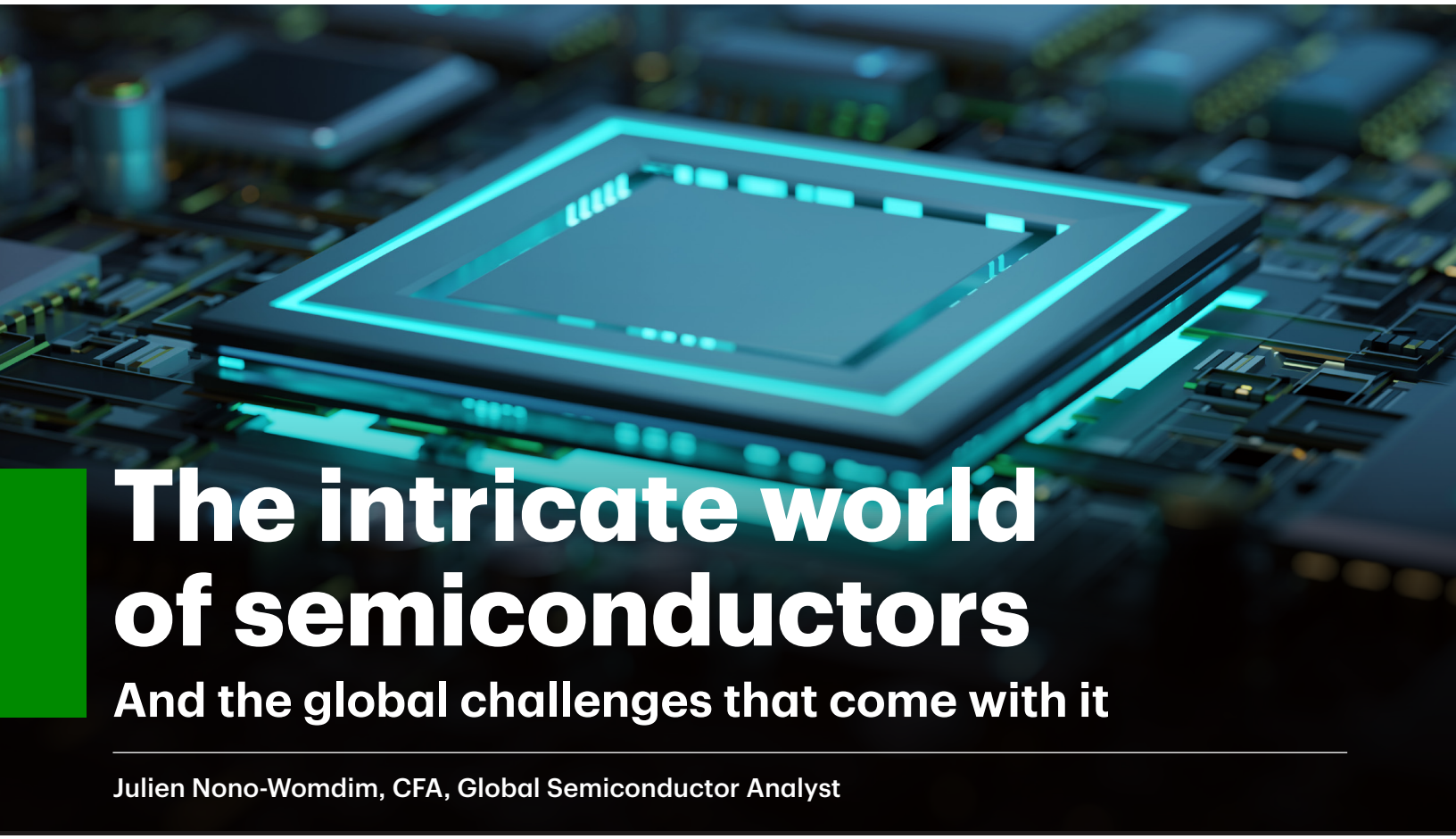


The intricate world of semiconductors

And the global challenges that come with it

Julien Nono-Womdim, CFA, Global Semiconductor Analyst

At a glance

- Semiconductors are a US$ 550 billion market[1] which has historically grown at about twice the rate of global GDP[2], a trend we think will persist for many years to come
- Though the majority of semiconductor demand is led by consumer products, going forward we anticipate incremental demand will be driven by a wider set of end-markets
- In 2020, global supply chain disruptions emerged following the onset of the Covid-19 Pandemic which led to shortages of critical semiconductors
- TD Asset Management Inc. (TDAM) is of the view that the historical outperformance of the industry will persist over time as semiconductors are the enablers of a technology-led future, and the rapid change in technology leadership requires an active portfolio management approach to capture the industry outperformance

It is hard to imagine a world without computers, smartphones and the countless electronic devices that make human life more productive and more enjoyable. The invention of the transistor in 1947 followed by the first integrated circuit a decade later have been two of the most important innovations in modern history. 60 years later, very few facets of life can function without the use of semiconductors and governments around the world have started paying close attention.

[1] Semiconductor Industry Association (SIA) 2022 Factbook

[2] Bloomberg Finance L.P. TDAM

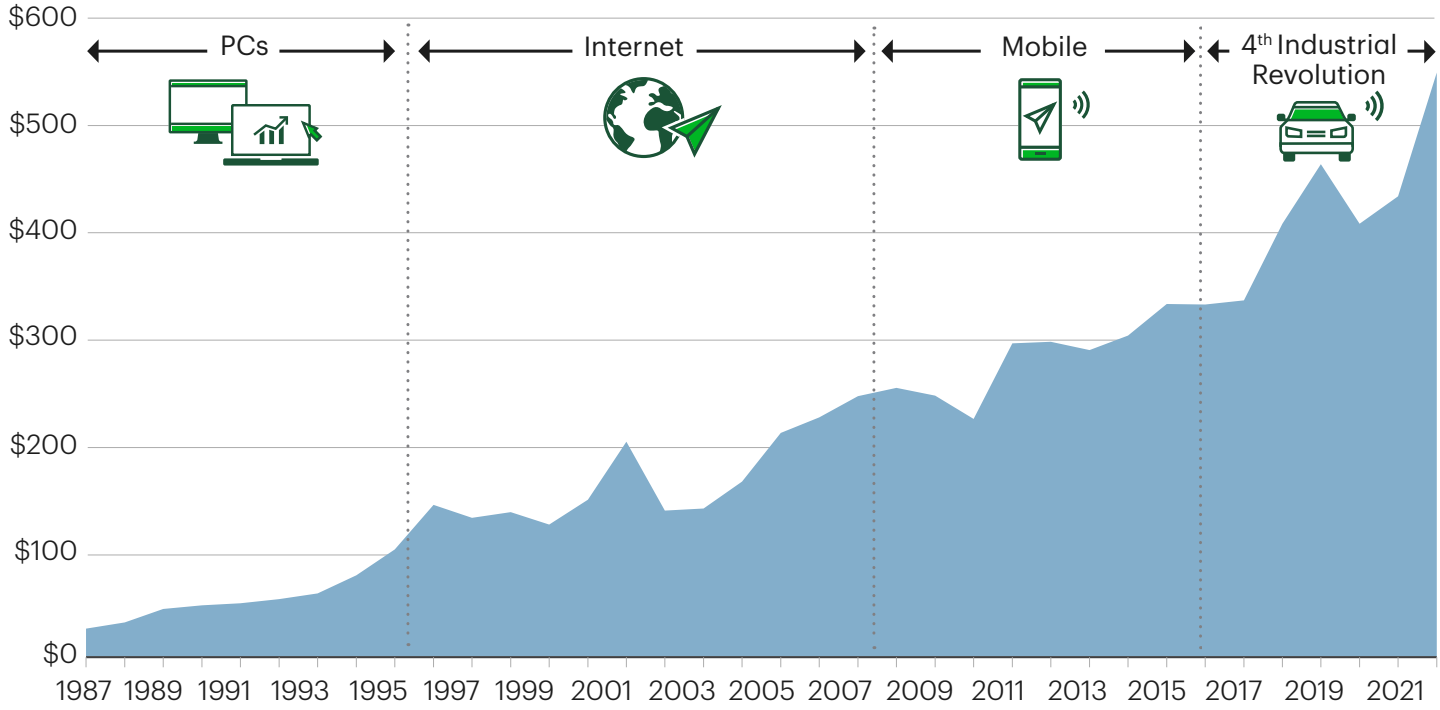
How did we get here?

Semiconductor devices are electronic components that enable the transfer of information and decision-making for electronic devices. Following the invention of the first integrated circuit in 1958, the number of transistors – which are building blocks for semiconductors – that can be placed into a microchip has doubled approximately every two years, following an axiom known as Moore's Law. As a result, the performance, cost, and power consumption of electronic devices have all improved exponentially and have expanded the number of use cases which can range from scientific research to military applications.

Modern computing is built on layers of abstraction with hardware sitting at the base layer followed by an instruction set, an operating system and then software. Though most end-users only interact with software, the billions of transistors that are invisible to the naked eye are what have allowed software to continuously improve in complexity and utility.

Today, semiconductors are a US$ 550 billion market[1] which has historically grown at about twice the rate of global GDP[2], a trend we think will persist for many years to come as more powerful semiconductors drive more semiconductor-intensive applications. As these applications become more powerful and complex, they in turn require more semiconductors. From an end-market perspective, semiconductor demand is bucketed into a few categories: personal computers, communications, automotive, consumer electronics, and industrial and military uses.

Yearly semiconductor sales (USD in billions)



Source: World Semiconductor Trade Statistics, TDAM. Data as of Dec 31, 2021

[1] Semiconductor Industry Association (SIA) 2022 Factbook

[2] Bloomberg Finance L.P. TDAM

Demand

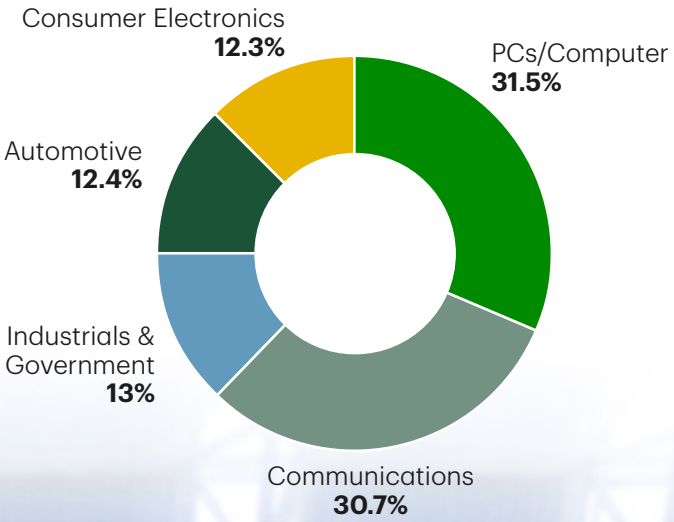
Demand coming from all angles

Though the majority of semiconductor demand is led by consumer products, going forward we anticipate incremental demand will be predominantly driven by a wider set of end-markets such as industrials, automotive and health care, to name a few. The basis for this view is threefold:

1. The decline in compute costs has allowed the creation of new business models that are natively digital and that will continue to represent an increasing proportion of global GDP – online retail for example.
2. The increases in compute power and performance are improving existing industries such as factory automation via robotics and drug discovery, using advanced analytics and increasingly various forms of artificial intelligence.
3. Environmental issues and decarbonization efforts are resulting in higher semiconductor intensity to tackle climate change. Electric vehicles have over 2 times more semiconductor content[3] than their internal combustion engine counterparts. Additionally, solar panels, wind turbines and energy efficiency sensors are all drivers of incremental semiconductor demand going forward.

> Today, semiconductors are a **US$ 550 billion market[1]** which has historically grown at about twice the rate of global GDP[2]

Semiconductor sales by market



[1] Semiconductor Industry Association (SIA) 2022 Factbook

[2] Bloomberg Finance L.P. TDAM

[3] McKinsey & Company, Mobility trends: What's ahead for automotive semiconductors. April 2017.

Source: Semiconductor Industry Association (SIA) 2022 Factbook

Comparative advantages between nations

In economics, output is often measured as a function of labour and capital, and as the quantity of either input increases, so does economic output. We are of the view that machine learning and artificial intelligence (AI) are either a substitute for labour or have a multiplicative effect on labour productivity. The great economies of the 20th century were industrial economies whereas the great economies of the 21st century will be digital economies. In essence, nations that have leadership positions in these technologies will not only have a comparative advantage in the production of goods and services but also in their ability to fight diseases and climate change.

In recent years we have seen the cost of AI training models decline substantially. Between 2017 and 2021 the cost of an image-classification system decreased from $1000 to cost only $4.60 in 2021. This is a trend that is observable in other areas of AI such as speech recognition and search engine recommenders[4].

The innovation we have seen in semiconductors is the result of scientific breakthroughs and highly complex manufacturing processes with a high degree of industry co-integration. Unlike most consumer goods, semiconductor chips are very small, which allows them to be transported to different countries through various steps of the manufacturing process, while the design of a chip is an electronic file that can be easily shared.

Semiconductor companies are therefore distributed globally and specialize in a specific part of the manufacturing process.

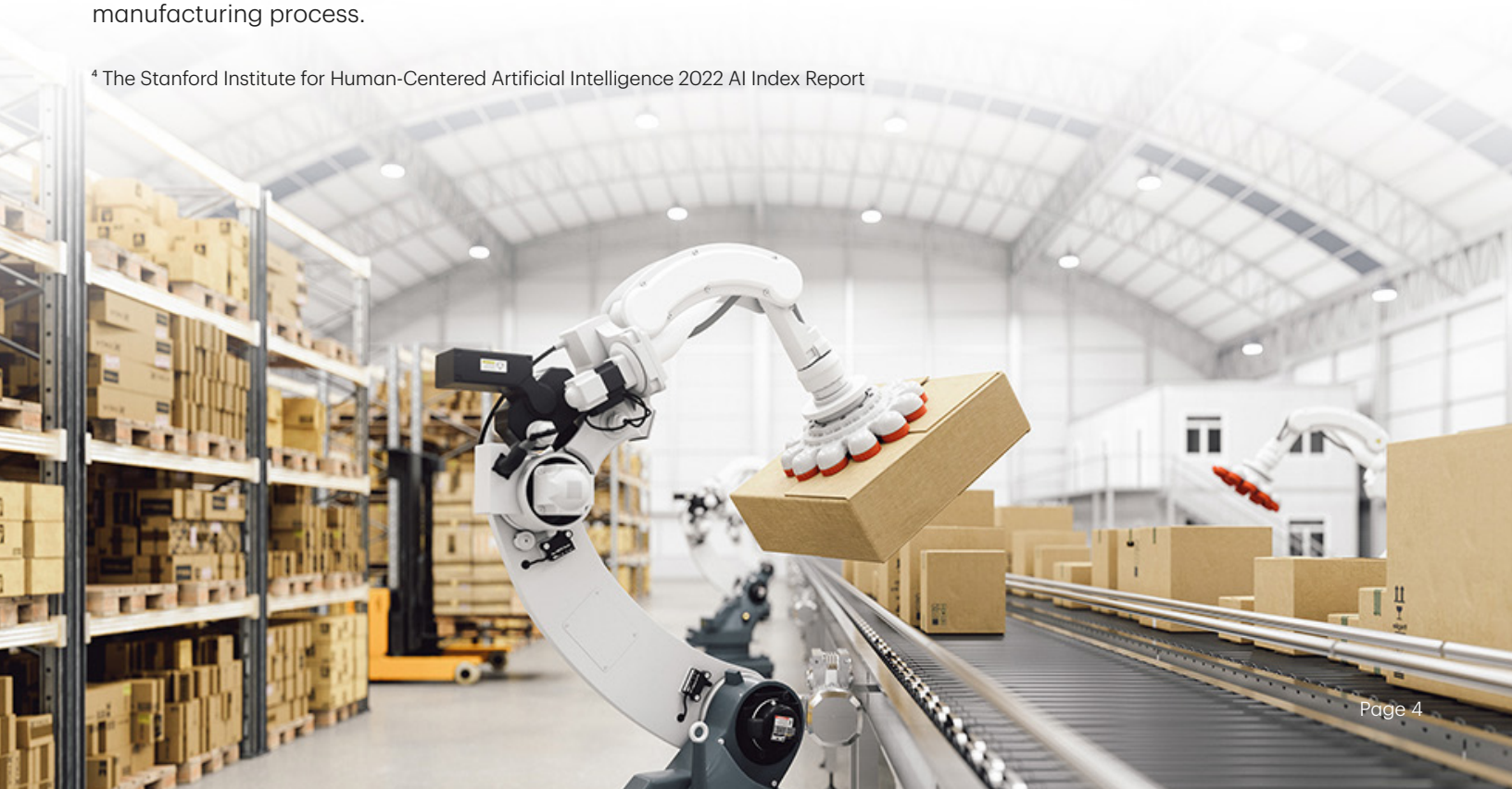
At a high level, there are three sets of companies in the industry. Companies that:

1. Design semiconductors
2. Manufacture semiconductors
3. Provide the materials, equipment or software for design and manufacturing

The complexity has led to the formation of natural monopolies and oligopolies within critical parts of the supply chain. The industry structure is vulnerable to exogenous shocks, should any geopolitical conflict or natural disaster occur as we have seen with the Covid -19 Pandemic and the Russia-Ukraine conflict.

> The innovation we have seen in semiconductors is the result of **scientific breakthroughs and highly complex manufacturing processes with a high degree of industry co-integration**

[4] The Stanford Institute for Human-Centered Artificial Intelligence 2022 AI Index Report



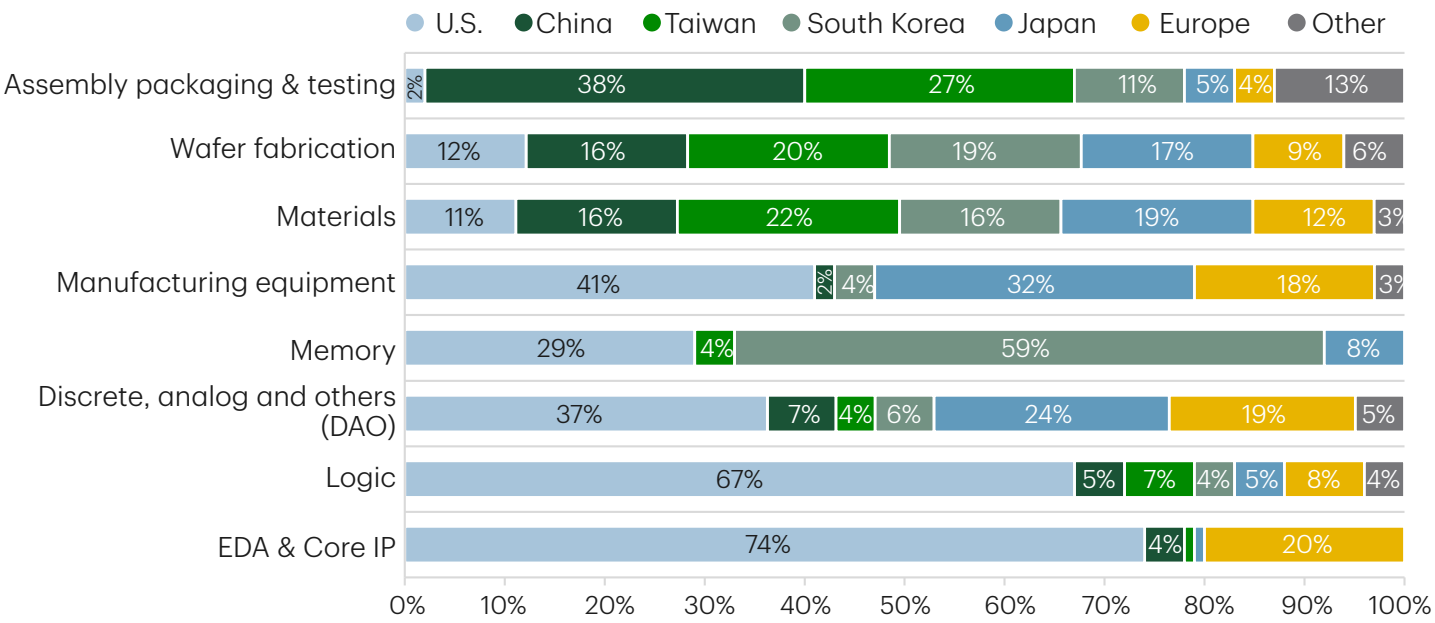
A global effort

The U.S, is the leader in global semiconductors, accounting for over 45% of industry revenues. But from a manufacturing standpoint, U.S capacity has fallen to 12% from 37% since 1990. Today, 75% of semiconductor manufacturing is done in Asia and nearly all the most advanced semiconductors are made in either Taiwan or South Korea.

Asia's leadership in manufacturing has been partly driven by government subsides, given the high capital outlay to design and manufacture semiconductors.

It costs over US$500 million to design a chip and over $5 billion to build a semiconductor manufacturing plant. Since 2011, China has provided the industry with over $100 billion in subsidies towards manufacturing, assembly, and testing, reaching a near 40% share of semiconductor assembly, packaging and testing and over 15% market share in wafer fabrication. Whats more, China is not alone in its active investment in the industry within Asia[5].

Semiconductors - a global effort



Source: Boston Consulting Group, Semiconductor Industry Association, Strengthening the Global Supply Chain in an Uncertain Era, April 2021.

[5] Source: Global Foundries, Delivering Pervasive Semiconductors for Humankind, October 2021, Boston Consulting Group, Semiconductor Industry Association, Strengthening the Global Supply Chain in an Uncertain Era, April 2021, McKinsey and Company, Semiconductor design and manufacturing: Achieving leading-edge capabilities, August 2020, Roadmap to 2050: Canada's Semiconductor Action Plan, Industry Report & Recommendations November 2021, Canada's Semiconductor Council

Today's challenges

In 2020, global supply chain disruptions emerged following the onset of the Covid-19 Pandemic, which led to shortages of critical semiconductors, given production disruptions and border shutdowns. One example of an industry hit hard from shortages is the auto industry. A modern car has over 1,000 semiconductor components, which include safety, infotainment, and powertrain components. The unavailability of some components has had a cascading effect on the entire supply chain and over two years later, the industry continues to face pockets of supply imbalance.

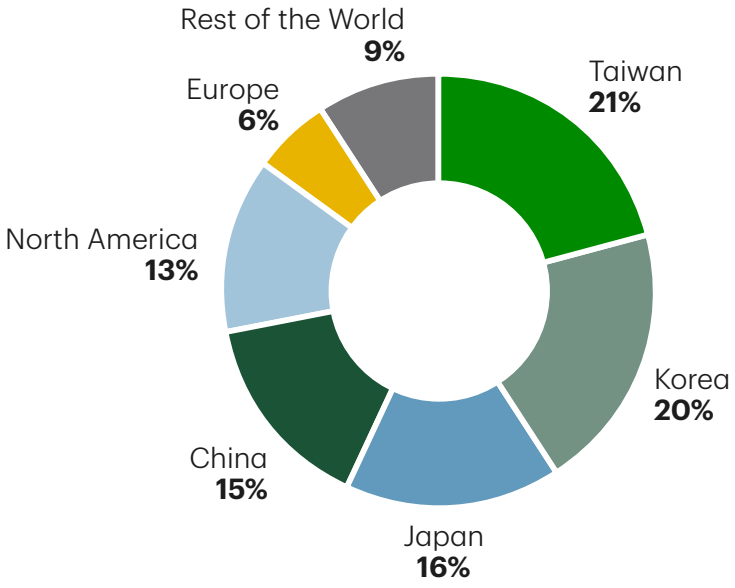
Bringing it back home

The pandemic was a catalyst for users of semiconductor products to recognize the critical importance of these inputs into their business at the corporate level, while on the global geopolitical stage, countries came to further appreciate the critical nature of semiconductors in the functioning of a modern society. Compared to other industries, the U.S and European semiconductor industry have a small manufacturing footprint. As of December 2020, Both the U.S and Europe accounted for over half of the global semiconductor market but together account for less than 20% of semiconductor wafer production.

In response to the challenges and risks posed by a shortage of semiconductors, the European Union's Recovery and Resilience Facility has promised at least €135 billion for digital transition and improving semiconductor self-sufficiency. In the U.S, the recently passed CHIPS Act will provide $54.2 billion in subsidies and an estimated $24 billion in tax credits for the U.S semiconductor industry through 2027. The primary objective of the bill is to stimulate U.S based semiconductor production. The CHIPS Act is part of the broader $280 billion CHIPS and Science act of 2022 which is aimed at expanding domestic technology research and development.

"Covid-19 catalyzed a newfound appreciation of the importance of semiconductors in the functioning of modern society

Wafer capacity by region



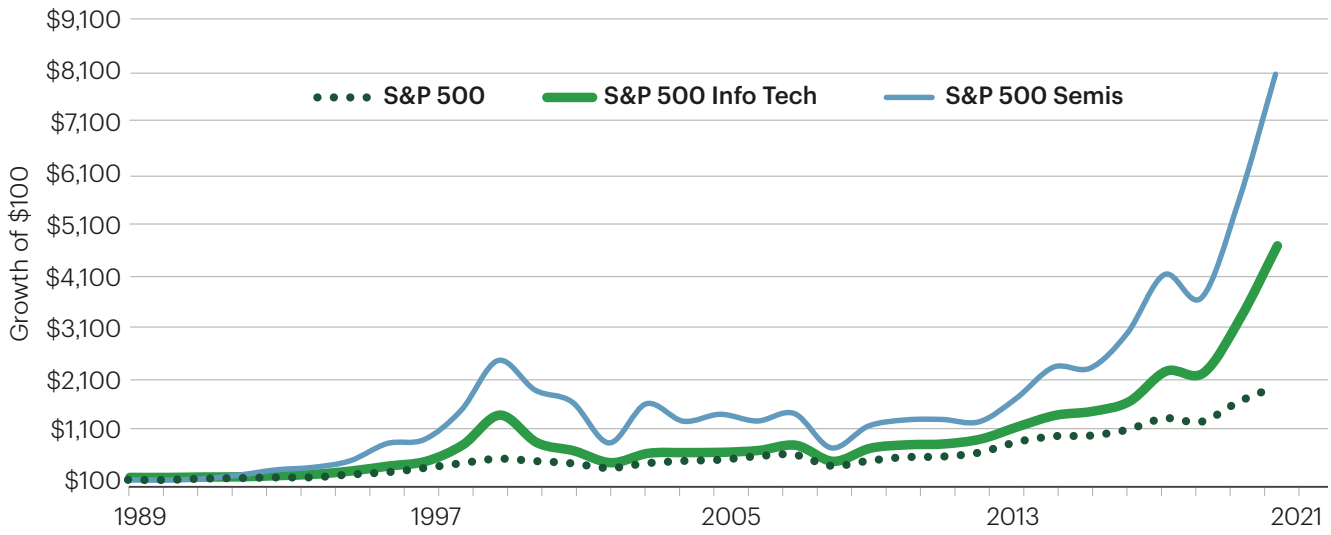
Source: IC Insights. Data as of December 31, 2020.

Investment implications

Over the last 30-years we have seen semiconductor equities materially outperform their Information Technology peers and the broader market. From January 1990 through December 2021, S&P 500 Index semiconductor stocks have compounded annually at 16.2% vs. 13.8% for Information Technology and 10.6% for the S&P 500 Index. More recently, over the last decade, semiconductors have also maintained their outperformance.

The drivers of this relative outperformance have been the critical nature of the industry, which has allowed for sustained revenue and earnings growth, an attractive industry structure, which has led to market-leading returns on invested capital, and most importantly continued innovation.

Outperformance of semiconductor equities



Source: Bloomberg Finance L.P. Data as of Dec 31, 2021

How quickly things can change

10 years ago, Intel held technology leadership in logic chip manufacturing and today Taiwan Semiconductor Manufacturing Co. (TSMC) is the leader. TSMC was quicker to adopt ASML's extreme ultraviolet lithography equipment and was therefore able to advance Moore's Law at a faster cadence.

Similarly, 20 years ago Canon and Nikon held strong market shares in Lithography – a critical semiconductor manufacturing step – and today both companies have receded market share and are unable to produce the most advanced lithography machines, with ASML holding 100% of market share in Extreme Ultraviolet Lithography.

> It took 50 years for semiconductor sales to reach $500 billion in annual production sales and over the next eight years, the industry **is expected to double to $1 trillion in sales.**

It took 50 years for semiconductor sales to reach $500 billion and over the next eight years, the industry is expected to double to $1 trillion in sales[6], driven by the continued proliferation of electronics and the emergence of new technologies. Against this backstop, we see evidence that the historical outperformance of the industry will persist over time as semiconductors are the enablers of a technology-led future. We believe the rapid change in technology leadership requires active portfolio management to capture the industry outperformance.

The investment case for semiconductors has rarely been stronger. As the global economy continues to prosper in an increasingly digital and sustainable manner, semiconductors will remain indispensable. Although the recent bout of underperformance in technology has been puzzling for many investors, with the S&P Information Technology sector down 22% YTD and the S&P Semiconductor Industry Group down 34%[7], long-term investors should consider having a close look at these companies. Putting together the powerful and secular drivers for semiconductor companies while keeping in mind the increasing politization of the industry and rapid changes in technology leadership, the case for an active portfolio management approach becomes glaringly apparent ■

[6] McKinsey and Company, The semiconductor decade: A trillion-dollar industry, April 2022.

[7] Bloomberg Finance L.P. Data as of August 31, 2022.

Growth

Connect with TD Asset Management

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