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The Semiconductor Industry: Crisis and Deglobalization

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Abstract
The semiconductor industry demonstrates a challenge to globalization, a concept that dominated strategy in manufacturing since the early 1990s. In 2023 the semiconductor industries in Asia, the USA, and Europe were facing large-scale supply shortages and long-term competitive changes. The semiconductor industry had grown to be a truly global industry since its beginnings in the 1960s supplying computer chips, core components for computing, consumer electronics, manufacturing, and service industries. Semiconductor manufacturing was dominated by very large manufacturers in Taiwan, China, Korea, and the USA. Global supply sourcing had worked well as demand expanded in the 1990s and early 2000s. But by 2022, coinciding with the Covid-19 global pandemic, the industry faced internal and external challenges. Competing models of computer chip production had emerged and at the same time, the security of global supply had become an issue. Geopolitical tensions and logistical concerns had led governments and businesses worldwide to wonder whether re-localizing the global semiconductor industry to assure domestic competitiveness and long-term supply independence would be a better solution. This paper presents a basis for assessing the feasibility of re-localization.

Keywords: semiconductor, high-technology, globalization and deglobalization, competitiveness, geopolitical issues

Nobody wants World War III, but… "*95% of the… microchips are made in Taiwan, which has a monopoly on the digital economy… I'd be open to using US forces to fight for Taiwan...*" US Sen. Lindsey Graham [1]

Introduction: The 2021-22 semiconductor supply crisis

In 2022, Taiwan produced over 60% of the world's semiconductors and over 90% of the world's most advanced microchips [2]. However a crisis was looming. As a consequence of Chinese intentions to take control over Taiwan, this advanced manufacturing was being threatened. If the threat proved true, the key assumption of globalization that a sustainable supply from worldwide sources would always be available, would no longer be valid. What could Taiwan Semiconductor Manufacturing Company (TSMC) do to preserve its position? How should the world respond, if chip shortages could seriously affect the world supply of electronics goods?

What could the regions of the world do to ensure the supply of semiconductors? How well were the regions equipped to make up for the potential loss of Taiwanese advanced semiconductor chip production? How far was globalization itself under threat? Were industries really so dependent on semiconductors? If so, would a move towards an alternative model focusing on the security of supply be the future? Would home production or sourcing from regional suppliers be feasible? Were countries and their respective regions collectively capable of replacing the now well-established global model for the supply of semiconductors?

The period 2020-22 turned out to be pivotal for the semiconductor global supply. A worldwide shortage of semiconductors was affecting businesses around the world. This shortage had been caused by a number of factors, triggered by a global pandemic, geopolitical tensions, and logistical problems. Managing a global supply chain became an issue of concern to companies and governments worldwide. The disruptive effects of shipping delays had already been exemplified by the blockage of the Suez Canal in the Spring of 2021, causing not only a backlog of several hundred container ships but also significant delays of sometimes several weeks in the delivery of all categories of imports. The Covid-19 pandemic and the reduction in world trade caused by travel constraints hit worldwide trade. In addition, geopolitical issues which caused tensions to rise affected major suppliers such as TSMC. The Russian invasion of Ukraine created additional major concerns about the security of global supply chains. Governments and manufacturers worldwide, realizing the security of semiconductor supply was their most important issue, began to focus on opportunities to secure supply chains by manufacturing their own semiconductors to serve their domestic markets, effectively deglobalizing what had been, up to that point, a truly global industry.

Given the genuine concerns of a potential long-term worldwide shortage of semiconductors, governments, and major suppliers were rapidly enacting plans to assure sufficient supplies of microchips. The pressures to deglobalize were reversing the trends towards global supply which had driven the semiconductor industry since the use of computers and consumer electronics became more widespread in the 1980s. Several key questions emerged. Should each continent become a supplier of semiconductors? Could a region such as Europe establish itself as a global supplier, or would European firms have to rely on traditional partners such as the USA and Asia to be their source of investment and supply? Would it be sufficient or even feasible for governments to provide the huge financial commitment required to develop semiconductor manufacturing hubs? Would skill shortages and logistical problems in the supply chain restrict the ability of new entrants to grow? The growing sophistication of buyers worldwide and the critical factors of security of supply were beginning to reshape and refocus the semiconductor industry. The location of an industry had never been so important to its customers.

The growth of the semiconductor industry - The demand side

The semiconductor, integrated circuit, and microchip process

"A microchip is a set of electronic circuits on a small flat piece of silicon… and contains billions of transistors". [3] Primarily because of silicon, semiconductors have a conductivity that can be controlled. Semiconductors are provided with integrated circuits, otherwise known as microchips, to provide the computer chips with operational control for operational processes and memory. The benefit of the microchip is that it enables product designers to condense the product size while driving the control of electronic products with various designs. Their application is unlimited in terms of capturing, processing and transmitting data.

The origins of the semiconductor industry

Semiconductors first appeared in the early 19th century [4], [5] following the discovery of electrical conductivity using conducting chemical elements such as silicon and germanium, and gallium arsenide. The science of semiconductors became commercially useful in photographic light meters in the 1930s [4]. The semiconductor industry emerged in the 1960s with the growth of computers and fabricated semiconductor devices such as transistors and integrated circuits (IC). Since silicon is the second most abundant element on earth after Oxygen [6], silicon became the main raw material for the IC industry [7].

The increasing use of computers

General-purpose computers were invented shortly after the end of the Second World War, and scientists, engineers and businesses began to see the advantages of automation across all business functions. The supply chain business model of the semiconductor industry started in the early 1960s as the use of computers and the focus on technology became more widespread. Technology's focus to play a wider role in the design, manufacturing, and accounting services was seen as the dawning of the third industrial revolution [8, p. 1]. As a result, the commercial beginnings of the semiconductor industry began to grow at the start of this era [9]. The semiconductor foundry model, where computer chips were designed and manufactured specifically for end-user customers, was started in the 1980s by the Taiwan semiconductor production houses and focused on the production services (foundry) for integrated circuit (IC) designers [10].

The competition within the semiconductor industry evolved from the 1980s and 1990s when semiconductors were seen as a standard component for memory chips and processors in computers. By the early 2000s, semiconductors had become a differentiated source of strategic advantage, providing specific competitive advantages for manufacturing and consumer products. By this time, manufacturers were under increasing pressure to differentiate their IC designs to compete with their product features.

Semiconductors in the 2000s: A global sourcing industry

Semiconductors were now the lifeblood of the global computing industry. They had expanded into many sectors where the capture of information had become the key to success. Starting in the early 1960s to supply a key component for computers, the semiconductor industry grew to become critical to every sector, either directly as a component of technology or indirectly as part of the manufacturing process. The semiconductor industry became one of the most important component industries in the world. The growth of social media and other forms of e-marketing meant that virtually every sector used some form of technology whether it be in design, manufacturing, marketing, accounting or finance. The demand for semiconductors grew together with the technology sector.

Semiconductors in the 2020s - Pressures to differentiate

Semiconductor chips were a core component of all technology, and this increasing need for diversification led to a highly competitive sector. In the environment of differentiation, customers required a quantity and quality of proprietary chips and the features that these chips could provide – these facts were becoming the main aspect of customer demand. However, customer issues also related to the security of supply, and there were relatively few, but very large suppliers worldwide.

By the early 2020s, the industry had already reached a turning point. It had developed from being a commodity-focused sector, where semiconductor chips were distinguished by speed and reliability, to a sector with focused differentiation where semiconductors provided key strategic focus based on each industry’s requirements. The semiconductor was no longer a commodity, differentiation was now key. Precision, speed, and size were the main advantages in the design to gain competitiveness for electronic products.

The pressures to deglobalize and to focus on the security of supply came at the same time as the strategic focus of the industry developed into a more customer-focused and niche-based industry. This created a competitive aspect with a small, but growing number of countries aiming to be competitive in semiconductor manufacture. However, the semiconductor industry was reputed to have a long learning curve to gain the necessary technological infrastructure and the expertise to develop and manufacture its product.

Semiconductor customers ranged from computer manufacturers to virtually any industry which required electronic technology. These included Apple, Samsung Electronics, Lenovo, BBK Electronics, Dell Technologies, Xiaomi, Huawei, and HP [11], and extended to all sectors and to firms of all sizes.

The 2020s - Security of supply

The main issue for manufacturers of any product requiring computer chips was the security of supply. This was a significant element because customers needed to rely on suppliers as a part of their logistics and supply chain, especially since semiconductor chips were playing a more and more important role in the value chain of differentiated technology-based products. For suppliers, the new entrants to semiconductor manufacturing remained a key long-term factor. Any investment in new semiconductor development and manufacturing was very high and the learning curve was long. However, because the semiconductor industry had become so important to governments and businesses worldwide investment money would be found and that would lead to increased choice for customers in the longer term.

Semiconductor manufacturing - The supply side

The high cost and the infrastructure required to develop and build semiconductors meant that the sector was dominated by very large corporations situated in a few countries. Taiwan, South Korea, Japan, and the USA each boasted a significant semiconductor manufacturing capacity. The semiconductor industry had become global, as demand from companies worldwide sought suppliers from diverse geographical locations.

The global semiconductor industry was dominated by companies from the United States, Taiwan, South Korea, Japan, and the Netherlands. Companies such as Intel, Advanced Micro Devices (AMD), Texas Instrument (TI), TSMC, Samsung, National Electrical Code (NEC), and Philips were some of the top semiconductor companies [12]. During the initial stage of semiconductor chip production, companies set up production lines for their own internally designed chips such as Intel and AMD (see Figure 1). They had an in-house production model which since the 1980s had evolved into what had become known as the foundry production-service model.

The semiconductor industry comprised firstly the raw materials suppliers, who were primarily suppliers of silicon; secondly, the production equipment manufacturers, who primarily produced machines that could lay thin wafers of integrated circuits onto semiconductor chips; and thirdly the testing equipment suppliers, who supplied quality control and circuit testing machinery. Each of these was a high technology sector. The cost to set up a semiconductor foundry was very high [13] and the learning/experience curve was very steep [14]. As a result, semiconductor foundries had high barriers to entry [15].

Differentiation in the semiconductor industry: Two competing models

The traditional semiconductor production model

The traditional chip design is set out in Exhibit 1. This model focused on the in-house design, production, and testing of IC chips by manufacturers producing their own branded chips which were designed for each targeted industry. Component manufacturers supplied electronics producers such as computer designers who designed, produced, and tested the computer chips and then made them available to consumers. Computer chip manufacturers focused on dedicated industry sectors. In the "traditional" model, the key differentiation was the perceived quality, reliability, and speed of the computer chip. Branding was based on a product designed for the particular market demand of an industry. An example is Intel with its "Intel Inside" slogan used to compete for personal computer microchips. However, the traditional model involved building costly in-house production lines. It was expensive for companies to maintain in-house both product design and production design capacity.

The "production-service" for chip design model

The "production service" model (also known as the "foundry", or "wafer fabrication" semiconductor production-service model) is shown in Exhibit 2. The key difference to the traditional manufacturing process was that specific customer needs were built into the design process, which were determined beforehand in consultation with the customers. This meant that the IC chips could be adapted to meet customer requirements, including features and attributes for each customer. In this way, custom (Application-Specific Integrated Circuits, also known as ASICs) chips were created with additional customer-determined features. The ASICs would be manufactured for the customer and would be sold under the customer's brand name, not the brand of the manufacturer.

This production-service model, which had evolved since the 1980s, (see Exhibit 2) provided integrated circuit (IC) production services to fabricate customized ASICs for chip designers. This business model removed the costly production setup and manufacturing process for the ASIC designers. This, in turn, reduced production costs, providing competitors with a faster time to market. The production process involved thin layers of silicon (wafers) which could be more efficiently manufactured for specific functions than the traditional in-house design, manufacture, and testing approach. In 2022, the top five semiconductor foundries were TSMC (55% of the market), Samsung (17%), UMC (16%), GlobalFoundries (7%), and SMIC (4%) [16]. The production-service model provided the foundation of the evolving supply chain for computer chip manufacturers.

Differentiation and profitability of semiconductors

The "traditional" and the "production-service" models are significantly different in the core values of the different production methods. The core value (see Exhibit 3) of the traditional model focused on the branding of the product (co-opetition citation needed) such as Intel, the computer chip based on quality and speed is key (e.g. Intel Inside). The net profit margin for this model was estimated at around 25%.

The core value of the production-service model shown in Exhibit 4 was trust [17]. The computer chip was seen as an integral component of the customer rather than a component added to the product by a supplier. For their product differentiation, the value chain focused now on privately designed chips to enhance market competitiveness. The net profit margin for this model was estimated at around 40%.

The emerging business model - The production-service model

A core value-added comparison chart of the traditional model and the production-service model is shown in Exhibit 5. It distinguishes the characteristics of the two manufacturing models, a standardized chip sold to technology manufacturers versus a customized chip sold through customer distribution channels. The production service model created two very important competitive advantages. It broadened its market expansions to all industries, and it reduced the cost of production for all product designers. These competitive advantages expanded the industry's economies of scale and formed the basis for its higher net profit margin without sacrificing the pricing strategy. Both clearly demonstrated the winning strategy of competitiveness which fitted the blue ocean strategy of expanding market boundaries while reducing cost at the industry level [18]. Aside from leading the development of the emerging production-service model, TSMC developed its 3-mn chips; Intel and Apple would be the first customers of this new technology by the end of 2022 [19].

Result: The emergent production service business model

The production-service model enhances market competitiveness

Due to the high demand for product differentiation to compete in the markets, the supply chain production-service model provided advantages for all the ASIC designers and their competitors:

- Chip designers could focus on their product designs without the burden of heavy investment into production operations.
- The designers reduced the cost of production.
- This model improved the time-to-market.
- The division of labor provided better quality products with advanced technology and research.
- Designers could focus on customers' demand and service.
- Transportation and logistics were shifted to the supplier.

A paradigm shift in the business model

The production-service model bolstered the supply-chain services. The paradigm shift was from stream-lined standardized products to the unlimited possibilities of differentiated products so that companies could compete using the foundry model. The product designers could outsource the design houses (consulting services to design a chip) and foundries (production) in close communication within a supply chain partnership to ensure quality deliveries. Critical supply-chain management activities included facilitating each of the following four value-adding services:

- The design house had to provide quality requirements to the production-service house.
- The design house had to provide the testing house with testing standards.
- The designers had to share confidential designs with the production-service house.
- The production-service house could drop the shipment to a final production house before the mass production was shipped to customers or drop-ship to designated distribution channels.

On the other hand, the production-service model provided a full service to all industrial designers for their own branded products. For example, with the well-enforced customer proprietary protection policy, TSMC empowered customers to compete in their marketplaces. This model encouraged competitors to innovate without the burden of production quality, high production costs, and lengthy time-to-market.

The supply dilemma

The industry had moved on to be dominated by the technologically ahead market leader, TSMC. Competitiveness would now be defined by having leading-edge semiconductors. However, the manufacture of such semiconductors required significant investment, growing markets, and the acquisition of high-level technical skills. As a result, countries were faced with a policy dilemma, whether they should continue to rely on global sourcing or focus on building domestic production.

The focus on regions for manufacturing semiconductors

In light of changing production models, customer demands, and geopolitical influences, Taiwan, the USA, and Europe were each aiming to upgrade their respective competitive position as semiconductor manufacturing locations. The key to competitive success for future semiconductor manufacturing depended on a highly intense, very strong manufacturing capacity. Designing and manufacturing semiconductors required an investment of US$ 50-100 billion per location, for the appropriate research, the development of infrastructure, and the availability of a highly skilled workforce. Demand for semiconductors was worldwide, (see Exhibit 6, Exhibit 7, and Exhibit 8), but supply required the support of an industry cluster that provided a value chain and also secured a supply chain from raw material to computer chips. In early 2023, Taiwan was still seen as the industry leader, but the USA and Europe were both looking to build their own manufacturing capabilities to secure the supply of semiconductors. Thus, each of these three regions aimed to expand and build capacity for different reasons. Each country needed to be competitive in the semiconductor industry to be able to secure the supply for the core industries represented by their customers.

An increase in worldwide demand for semiconductors was considered highly likely. But questions concerning the future of the semiconductor industry focused firstly on the differences between the traditional and the foundry business models and on how dependent industries would be on the emerging foundry model (see Exhibit 9 and Exhibit 10). Secondly, the question of whether countries could catch up technologically so as to be able to supply either traditional or foundry-based production. Would the industry be differentiated and what would this mean for customers and for manufacturers?

Both Europe and Taiwan had been followers in the chip industry that had originally been dominated by Silicon Valley in California. What set both Taiwan and Europe significantly apart, then as well as in the early 2020s, was their starkly different industrial ecosystems (see Exhibit 11, Exhibit 12, and Exhibit 14 for the regional sales data).

The semiconductor industry in Taiwan

Taiwan, the leader in the field of semiconductor production, could build on its position high up the semiconductor design and manufacturing learning curve, as a result of five decades of development of the foundry model. This technical lead, combined with Taiwan's very low labor costs gave Taiwan a significant first-mover advantage. The main producer, TSMC, became a service provider to manufacturing customers (see Exhibit 13 and Exhibit 15).

The requirements for success in the semiconductor industry and Taiwan's economic environment and semiconductor ecosystem were a perfect match, and by 2022, the ecosystem had been developed that provided Taiwan's success.

The key distinguishing features for Taiwan were the labor costs and the expertise of the Taiwanese. Labor costs in Taiwan were around one-third of those in the USA [20], [21]. Taiwan's low pay contributed to the low-cost production system along with the high technical skills of its workers.

Taiwan invested in STEM (Science, Technology, Engineering, and Math) and there was a strong partnership between the government and industry which dates back to the 1960s. In the 1970s, the Government provided infrastructure such as electricity, dams, highways for future economic growth, and a technology R&D research center (ITRI) [22]. The Government of Taiwan also provided support by having a consistent economic policy, which resulted in GDP growth, as well as universal healthcare coverage and education.

Taiwan's main weakness was its lack of experience in marketing and branding [9], and hence its reliance on production services, rather than on promoting its brand worldwide. Domestic demand was weak in Taiwan as the domestic market was small, and TSMC did not compete with its customers. Taiwan was also weak in international branding. Taiwan's technically good mobile phones, HTC smartphones [23], never achieved critical mass in terms of sales and never competed as a brand with Samsung and Apple.

Taiwan's future relied on precision machinery [24] and thus, it was a first mover into foundries. Taiwan had strong clusters of related industries and was well ahead of other countries with its production-service business model [25]. Taiwan had always been strong in the precision machinery industries and had strong support from the Government of Taiwan which had built industrial parks and infrastructure to support the linkage between research and industries such as the ITRI research center [26].

TSMC: Morris Chang, founder and long-time CEO of TSMC had built an empire. By the 2020s TSMC had grown from the early days of manufacturing semiconductors in the 1960s to being the dominant leader in the world's most advanced semiconductors [27].

TSMC was the most successful foundry among all wafer production-service companies. It was the leader of foundries with 55% of the semiconductor market shares [26]. One of TSMC's key success factors was that it had a rigorous policy on building trust with customers. They were able to protect a customer's confidential information and design to the highest management goal [9].

The TSMC business model was to fabricate the semiconductor ASIC chips and supply the chips to consumer product manufacturing companies such as Foxconn (also Taiwanese-owned) in order to finalize the consumer product manufacturing (See Exhibit 3 for the supply-chain flow). TSMC liaised with the customer (such as Apple) to design the microchip, ensuring that the design met the customer's requirements. Then, the microchip would be delivered to an assembly house similar to Foxconn so the final products could be made that were based on the consumer product's design. In addition, TSMC continued to invest in R&D in fabrication technology to be ahead of the industry.

However, TSMC needed to sustain its lead in the industry, and faced with the global supply chain and geopolitical issues, TSMC needed to determine what its future would look like. Taiwan had a strong supporting industry and many years of experience in semiconductor manufacturing, but moving abroad to set up manufacturing in other regions would not have such advantages.

The semiconductor industry in the USA

Conversely to Taiwan, the USA was very competitive in marketing and branding. For many years, the "Intel Inside" logo had dominated the personal computer market in spite of there being no significant quality difference between the major semiconductor producers. There had been a skilled workforce in Silicon Valley and in other areas of the USA for many years. However, the USA, and especially Silicon Valley, had very high labor costs resulting in high prices for its customers.

Demand for semiconductors was high in the USA, where consumer demands drove a very competitive industry and where competition between rivals was high. Demand was characterized by a lot of innovation in the US economy, a lot of research and development, and a lot of marketing and brand building. The US was the product market leader up until the 1990s [28].

The strategies of semiconductor manufacturers were well developed but they also needed to look forward to a newly differentiated demand for semiconductors. The US government provided a competitive environment for the industry by maintaining a freely competitive economy with minimum regulation. Competition in the sector was characterized by a high degree of rivalry and differentiation. US major semiconductor companies included Intel, AMD, Nvidia, Texas Instrument, and Micron Technology [12]. US demand had been rising [29] associated industries in the sector were plentiful and regions such as Silicon Valley provided fertile grounds for the development of technology clusters.

The main weakness of the USA was cost. A high GDP and a high technology economy with a highly skilled and abundant labor force had led to high-cost production In the technology sector, in particular, this meant that US firms had very high overhead costs when compared to Taiwan. Silicon Valley, the capital of technology [30], had very high labor costs that had been rising over the years [31].

In late 2022, it was announced that TSMC was setting up manufacturing facilities in Arizona. However other US manufacturers also wanted to expand, including Intel. Each manufacturer built on its own customer base and the technological catch-up with TSMC was a key objective. The big question now was what new strategies would emerge. In addition, the US had made commitments to provide the semiconductor industry with US$50 billion to support private sector investments in semiconductor manufacturing in the US [32].

The European semiconductor industry

In 2023, the semiconductor industry in Europe also had to respond to evolving demand for semiconductors and to prioritizing supply security. Whilst the semiconductor industry in Europe lacked the comprehensive manufacturing base that was long established in Asia and the USA, the European semiconductor sector still had a firm base. The countries of the European Union collectively represented the world's third largest economy, after the U.S. and China, but only accounted for 10% of the global chips market.

Although European countries were present in the global semiconductor value chain, the manufacture of semiconductors was still emerging. Building manufacturing facilities, either for the manufacturers' own brands, or foundry facilities to produce custom-made chips for clients, required significant investment, a network of existing customers, and the existing suppliers of the complex system of equipment and components. In addition, a long learning curve was necessary to master the manufacturing processes as well as the technologies involved in semiconductor manufacture. However, European firms were already present in several sectors of the value chain including design, an evolving sector with close links to manufacturing. Europe also had a significant presence in research and development and strong links to universities and technical institutes.

Demand conditions were different in Europe [33]. There was no major consumer electronics sector in Europe and, therefore, no need for the manufacture of semiconductors for this sector. However, the automotive and manufacturing sectors were also well established in Europe and together they amounted to more than two-thirds of the demand for semiconductors in Europe. They also represented the highest-growing sector in demand for semiconductors worldwide. Growing sectors in the automotive industry included electric cars and advanced driver and self-driver systems, each of which would require advanced and custom-made semiconductors. Growth in every sector of artificial intelligence also required advanced semiconductor manufacturing. Other sectors such as medical equipment, communications technology, and data centers, each requiring advanced semiconductor capacity, were also major customers in Europe.

There was no large-scale European manufacturing facility and this represented a significant deficit compared to the USA and Asia. However, presence in other sectors of the semiconductor value chain provided options for European countries. Given the size and scale of the semiconductor sector and the investment in research and development, it was unlikely that any country or region would be able to be totally self-sufficient or even be present in all sectors of the value chain, but the presence across the semiconductor ecosystem would present options. European firms had specialized in semiconductor design and manufacture such as sensors, power and frequency chips all of which required innovation but not reductions in size. The main manufacturers of semiconductors in Europe, Infineon, NXP, and STMicroelectronics, all produced semiconductors for the automotive and manufacturing sectors. Other semiconductors designed in Europe were manufactured by foundries in Asia [33].

The European Semiconductor Industry Association (ESAI) reported that European sales of semiconductors had increased 12% during 2022 and amounted to US$ 53.809 billion in 2022, compared to the worldwide total of US$ 574,477 billion, an increase of 3.3% [34].

Europe played a role in some R&D-intensive fields such as machinery (ASML was considered the leading edge in the Netherlands). The UK also played host to chip intellectual cores. There were strong fundamental research centers such as IMEC in Belgium, CEA-Leti in France, TNO in the Netherlands, and Frauhafer in Germany, all linked to universities.

Issues facing European countries focused on serving clients' needs in a rapidly evolving sector. Given the well-established demand base and the close links between design and manufacture, Europe was well placed to increase its presence in the semiconductor sector, but the lack of manufacturing capacity most likely required significant investment from a worldwide manufacturer such as TSMC or Samsung.

The benefits of increasing its presence in the semiconductor ecosystem would likely be significant. In addition to the security of supply and the opportunity to augment the home-grown ecosystem in conjunction with existing customers, improved presence in the semiconductor design and manufacture would lead to increased opportunities to develop the AI sector and expand the pool of knowledge and skills in the labor force. It would also attract more suppliers of machinery and components to this complex sector.

Germany: Germany had three major semiconductor clusters, in Saxony, Bavaria and Baden Wurttenberg. These represented the strongest semiconductor ecosystems in Europe with key customers being chip design, 5G technology, the automotive industry, and electric vehicles [35]. However, German companies still relied on semiconductor manufacturers in Taiwan and North America for the majority of their needs, something that was now perceived as a potential national security threat [36].

However, the European sector had started the process of catch-up. According to the Germany Trade and Invest, GTAI, Germany ranked amongst the world's top semiconductor manufacturers' locations, comprising device manufacturers, materials suppliers, components, and equipment. The entire value chain was represented. The German Government planned to invest Euro 50 billion to secure Germany's position as a semiconductor manufacturer. Semiconductor manufacturers were already present in Germany. These included Bosch, which had a production facility in Dresden which was Europe's first fully digitalized semiconductor manufacturing facility. The US manufacturer, GlobalFoundries, had a manufacturing facility in Dresden and in 2022 announced an increase in annual production from 400,000 to 1 million wafers, an investment of Euros 1.1 to 2.4 billion, primarily for the automotive industry, manufacturing, and mobile 5G technology and sensors. Infineon also planned to increase production at its Dresden site, targeting the same markets. Intel announced they would be establishing a manufacturing plant in Magdeburg with the option of building further manufacturing facilities (fabs) [37].

Other European countries: Netherlands hosted the semiconductor manufacturer NXP, with its headquarters in Eindhoven, producing semiconductors valued at US$ 7 billion for the automotive market and a further US$ 3 billion for the industrial and internet-related markets. NXP was also present in the communications and mobile markets and had co-invested the near-field communication (NFC) technologies with Sony, which enabled payments to be made from mobile phones and the secure storage and exchange of data [33].

ASML was another Dutch supplier with headquarters in Veldhoven, providing photolithography systems for the semiconductor industry worldwide and advanced chip technologies. Other smaller manufacturers include ASM International and BE Semiconductor Industries (BESI) [38].

Belgium had several companies specializing in design and components for the semiconductor industry. Outside of the EU, the British industry specialized in the design, intellectual property, research, and fabrication of compound semiconductors and was worth US$13 billion in 2022. The major chip designer in the UK was the world-renowned semiconductor designer company ARM.

The EU Chips Act 2023: The EU Chips Act 2023 aimed to increase the EU share of semiconductor production from around 10% to 20% by 2030 [39]. The Act 2023 provided both a legislative facility and Euro 43 billion funding aimed at leveraging the European semiconductor industry, specifically by supporting private-sector investment with public-sector funds. It addressed several areas of policy and investment. It supported research into AI and disruptive technologies, as well as supply chain development by supporting the transformation of research into innovation in semiconductor design. It also supported smaller businesses in the sector, the development of workforce skills, and encouraged equity investment and partnerships. The legislative aspects focused on the adaptability of state aid rules to allow for a private sector investment into this very high investment area [36], [38].

European government programs to increase semiconductor security of supply: Semiconductors, or "chips" in EU parlance, became a strategic supply issue as of 2020-21 not only for the EU as a whole but also for the potentially competing interests of governments of the key individual countries. The 2022 "Chips Act" proposed an EU-wide "comprehensive set of measures to ensure the EU's security of supply, resilience and technological leadership in semiconductor technologies and applications." For this purpose, the EU planned to spend up to US $ 50 bn over the following decade to achieve "Digital Sovereignty" [40].

Given the worldwide shortage of semiconductors in 2022, and the logistical and geopolitical issues that were being seen as the cause of the shortages, both governments and industry were forcing themselves to look at ways to improve their supply autonomy. Europe was seen as having entered the race of semiconductor design and production too late [41]. In 2022, Europe’s position was primarily as a user because of the lack of design houses and production facilities. However, opportunities were available for certain niches of the semiconductor industry. The most notable of these was in the development of the design houses sector [42].

Looking ahead: Beyond 2022

In the summer of 2022, the US and the EU presidents almost simultaneously announced their (close to) $50 billion Dollar/Euro chip investment plans. Both aimed to end the Covid-induced semiconductor shortage that had slowed almost all industries on both continents. They also wanted to re-shore (deglobalize) essential parts of the semiconductor value chain as well as catch up with Asia, ideally leapfrogging Asian countries, especially world market leader Taiwan with its pioneering TSMC. Whether almost similar investments would yield similar results for Europe and the US was another question.

The US had been the birthplace of microchips (Silicon Valley) and looked to be well-positioned to regain its original lead in this transcontinental race (Intel, Nvidia, Qualcomm, etc.). Conversely, Europe held a 10-12% world market share in all pertinent elements of the semiconductor value chain, from design to production. This was in stark contrast to Taiwan, the "gold standard" of the chip industry, due to their pioneering world market leader TSMC.

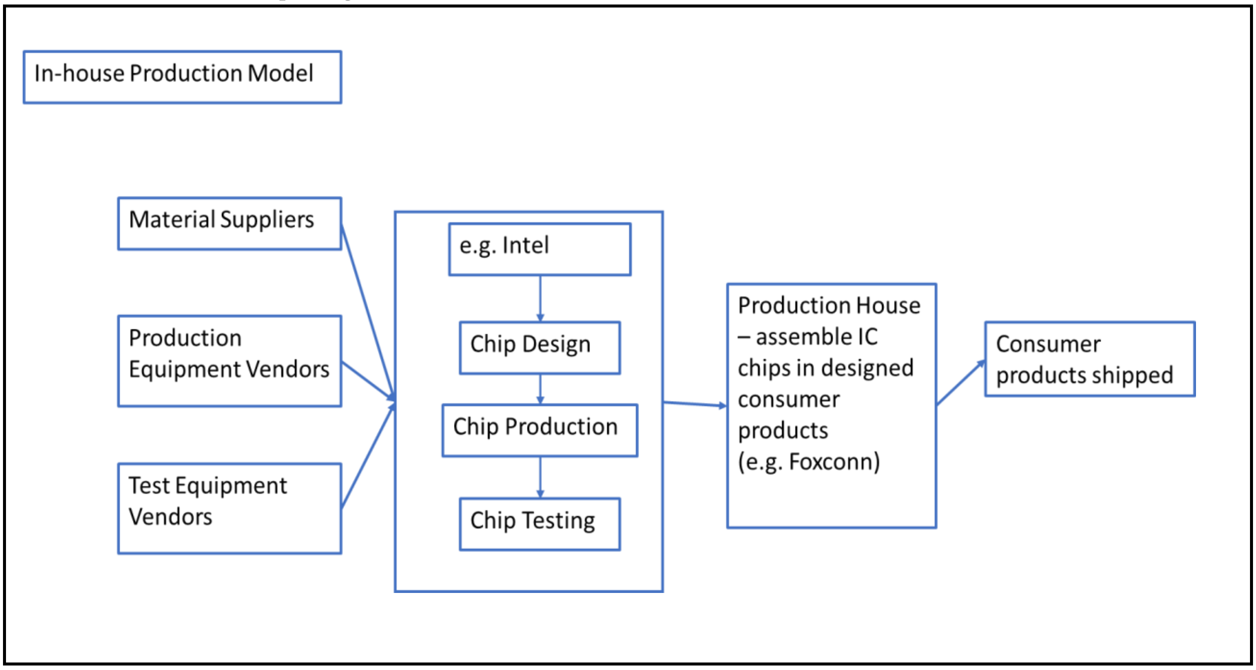
A subsequent comparison with Europe's situation highlighted the significant gaps and investments needed to catch up, let alone leapfrog Taiwan. However, investment in the semiconductor sector would only pay off if each country provided the infrastructure and skills to support it. However, money alone would not guarantee success. Taiwan had the technological lead with lower labor costs, the US had the necessary labor skills and manufacturing base, but with high labor costs. Europe still lagged behind in the chip design and production race. However, the decade beyond 2022 would most likely see a significant change in the worldwide semiconductor industry.

What were the opportunities and limitations on the response of the USA and Europe (i.e. what are their options)? To rely on TSMC and/or global trade in semiconductors? To build their own stand-alone semiconductor sectors?

If "striving to be the best" had negative consequences, how then should the three economic powerhouses of the world compete? Is there a formula for a win-win-win outcome? Could each location and its inhabitants win in their unique way, similar to the world car market? Deglobalization in the semiconductor industry was setting new parameters and the nature of competition was changing. Further questions to ponder upon are as follows.

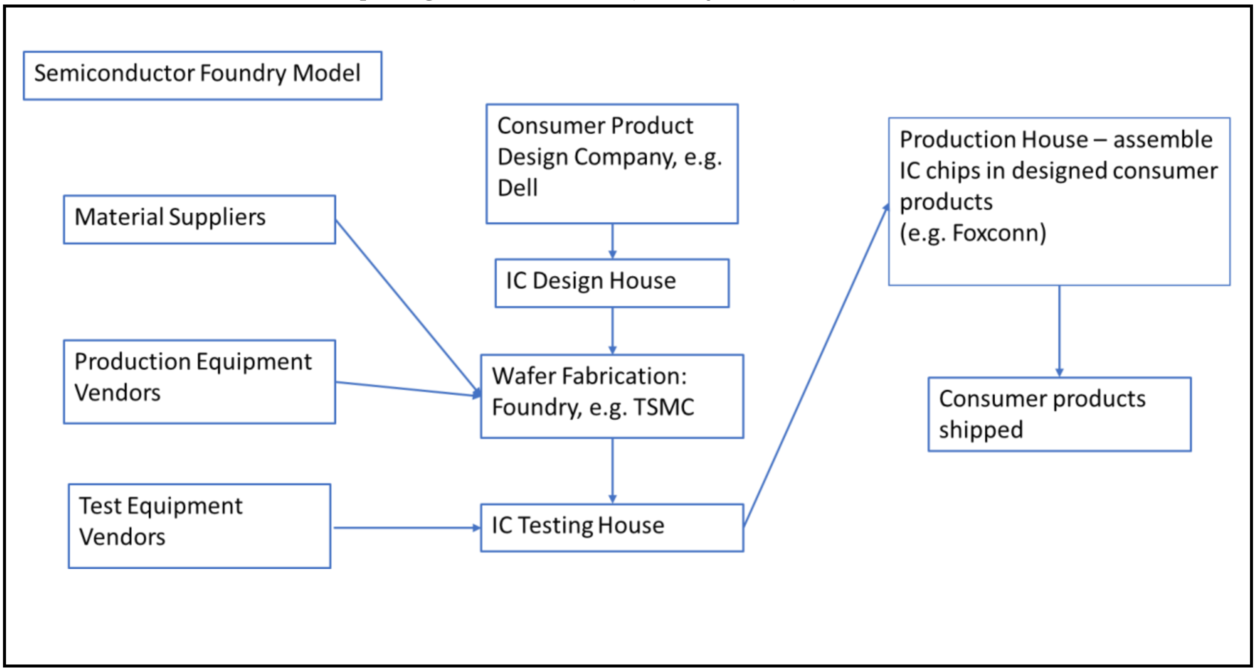
1. What should TSMC's strategy be regarding non-Taiwan manufacturing?
2. What new strategies would emerge from US manufacturers?
3. What strategic niches will there be for European manufacturers?
4. What effects will the European policy of $50 billion have on semiconductors?
5. What would represent achievable targets of European semiconductor manufacturing?
6. How do you access TSMC's strategy of multi-country production?
7. Does the semiconductor industry re-localization herald the end of globalization?

Exhibit 1. Traditional chip design business model



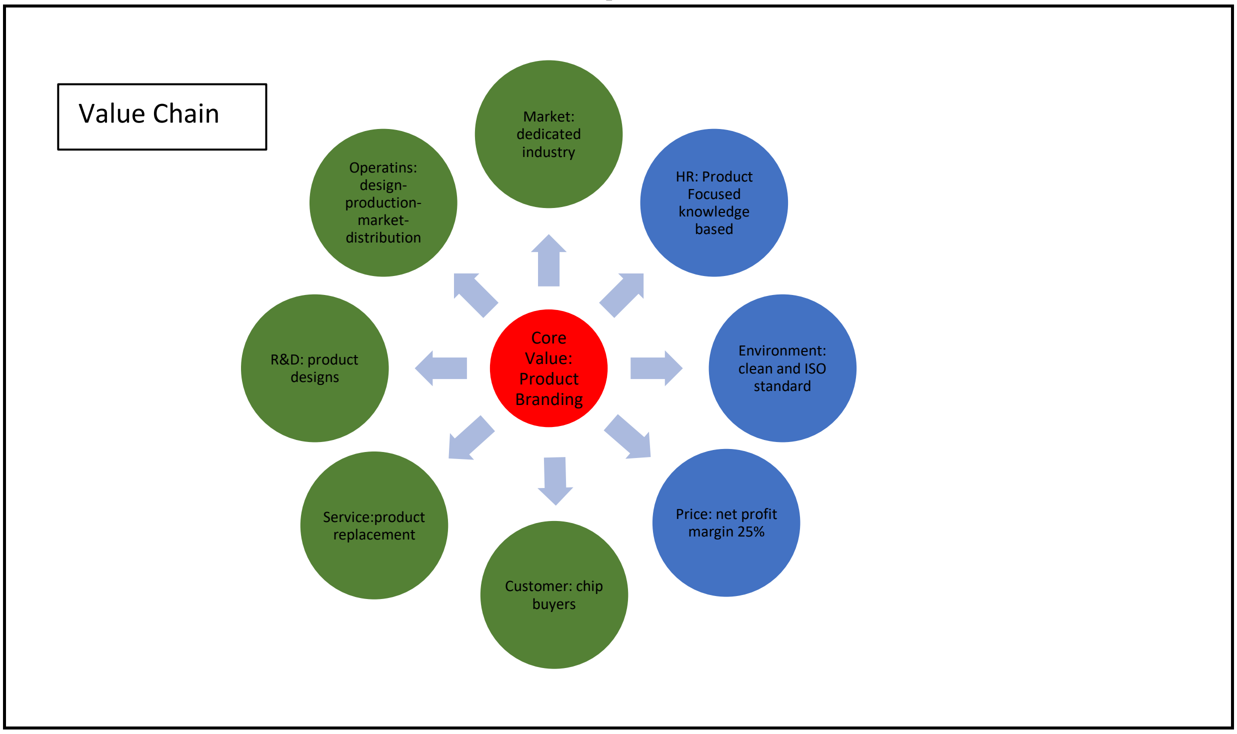
Source: authors' own

Exhibit 2. Production service chip design business model (foundry model)



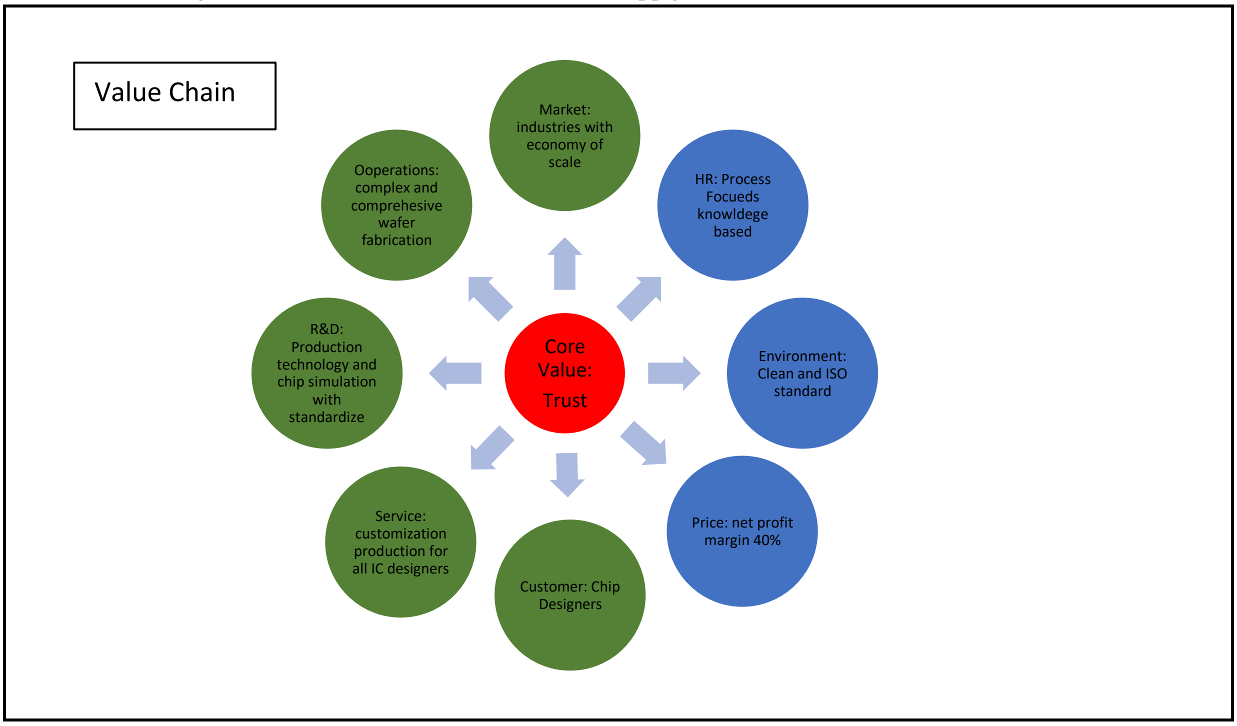
Source: authors' own

Exhibit 3. Traditional IC business model – Streamlined product



Source: [43]

Exhibit 4. Foundry business model – Production service supply-chain



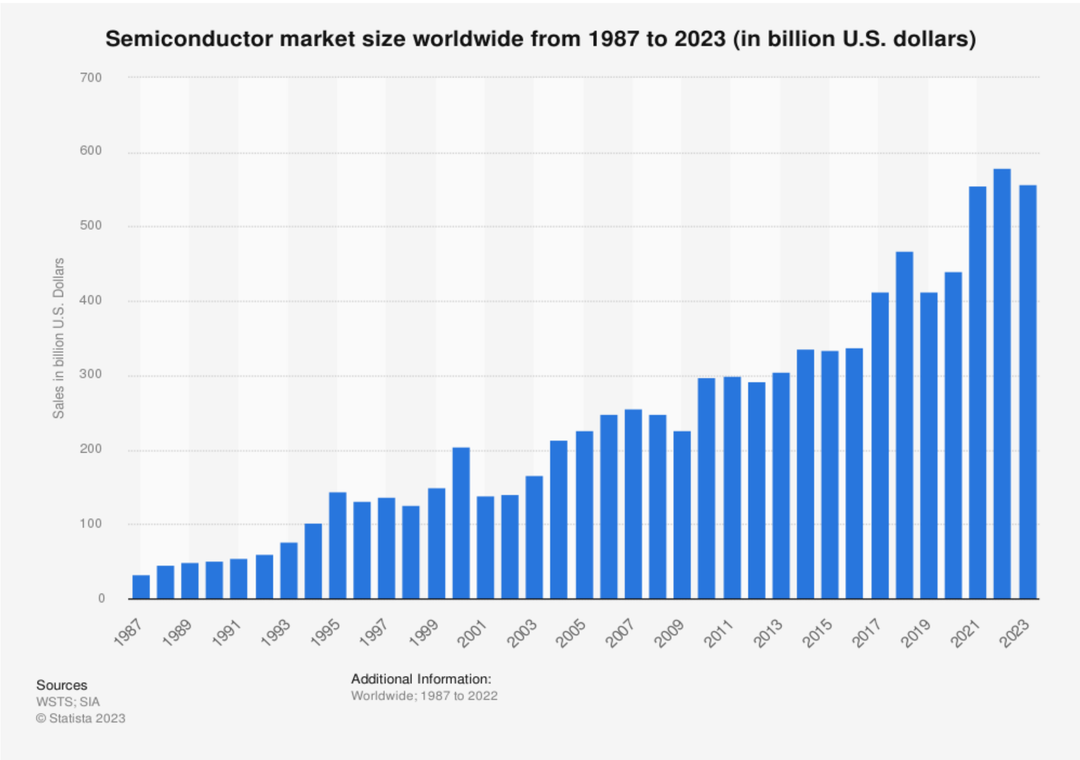
Source: [44]

Exhibit 5. Comparative table on stream-lined production model and supply-chain production service model

Characteristics	**Stream-Lined Production Model - Traditional**	**Supply-Chain Production Service Model - Foundry**
Market	Dedicated industry/Products	Industries with an economy of scale
HR	Product Focused	Process Focused
Environment	ISO Standard	ISO Standard
R&D	Product design focused on the product demand	Production process design focused on yield and quality demanded by the design houses
Customer	IC buyers	IC designers, reduced production cost
Service	Set the product standard	Customization
Price	Net profit margin: ~25%	Net profit margin: ~40%
R&D	Product features	Production technology and chip simulation with standardized layout modules
Operations	Streamlined design-to-distribution	Complex and comprehensive wafer fabrication
Core Value	Product differentiation	Designer's trust

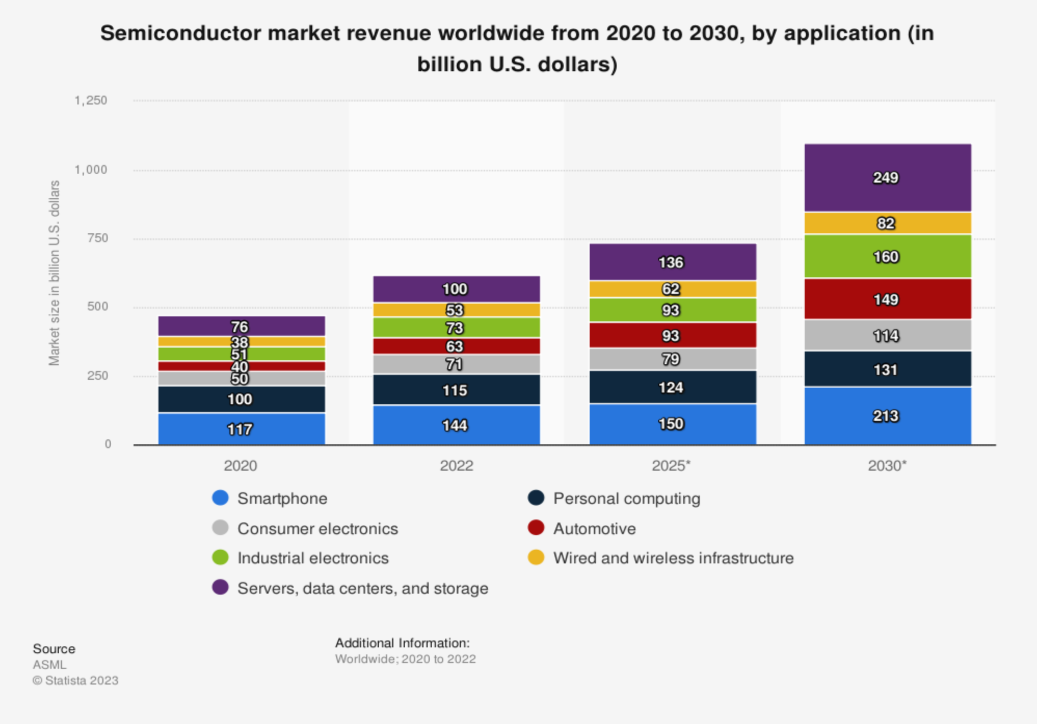
Source: [45]

Exhibit 6. Semiconductor market size worldwide from 1987 to 2023



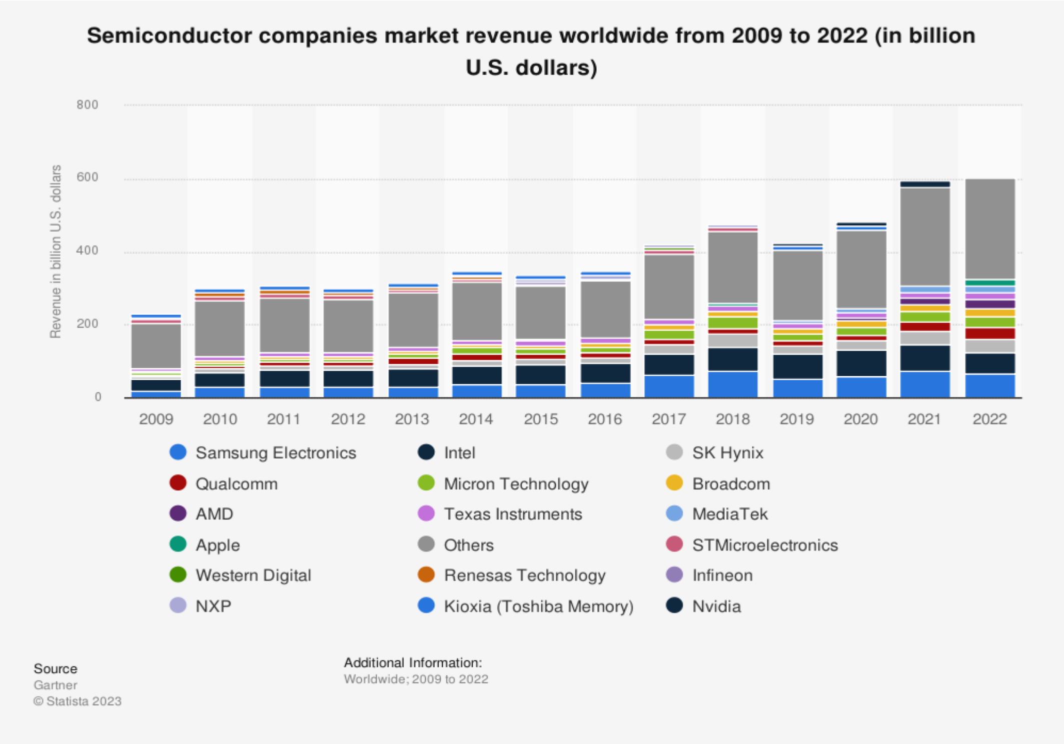
Source: [46]

Exhibit 7. Semiconductor market revenue worldwide from 2020 to 2030, by application (in billions USD)



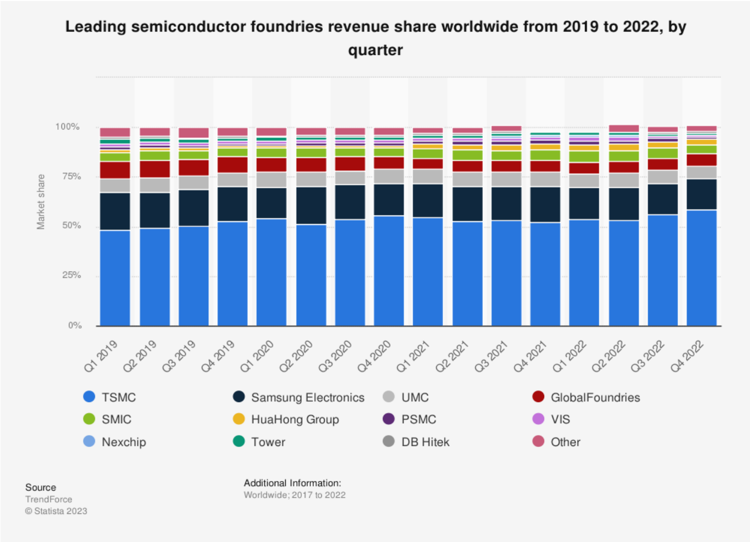
Source: [46]

Exhibit 8. Semiconductor companies' market revenues worldwide from 2009 to 2022 (in billion USD)



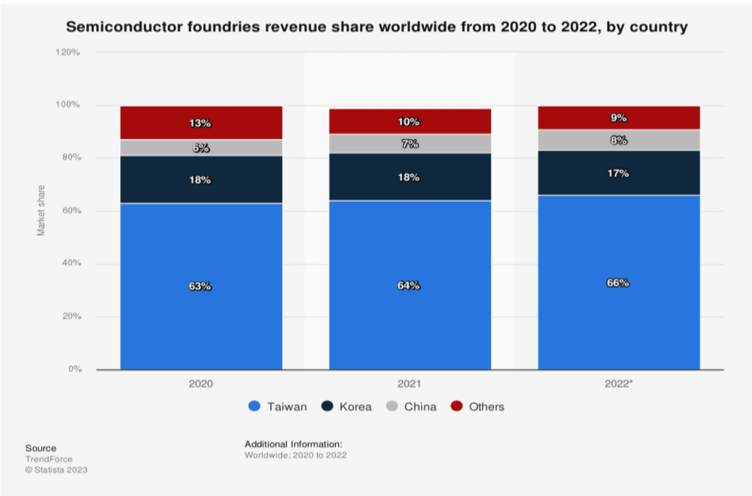
Source: [47]

Exhibit 9. Leading semiconductor foundries' revenue shares worldwide from 2019 to 2022, by quarter



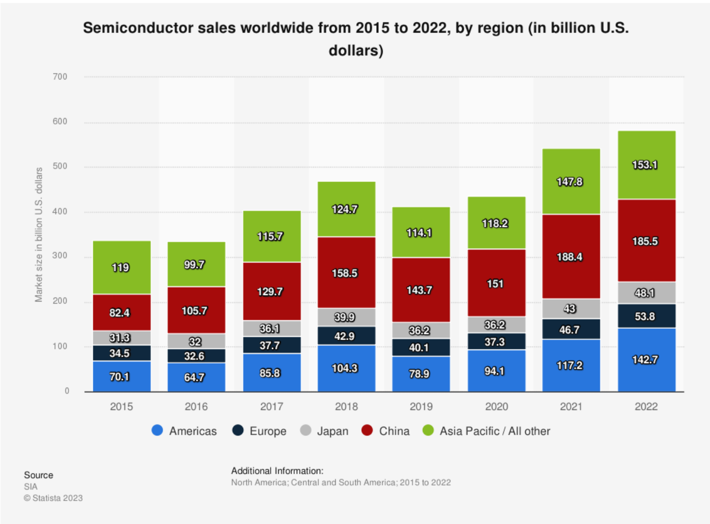
Source: [48]

Exhibit 10. Semiconductor foundries' revenue shares worldwide from 2020 to 2022, by country



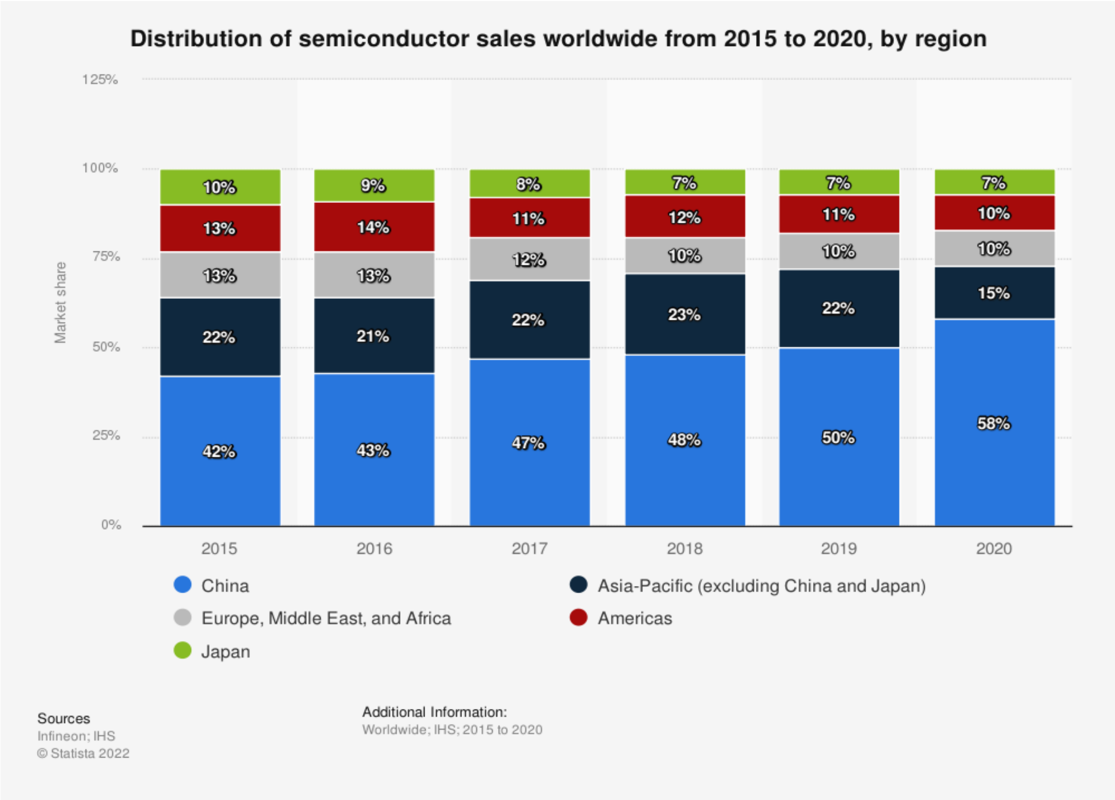
Source: [49]

Exhibit 11. Semiconductor sales worldwide from 2015 to 2022, by region (in billion USD)



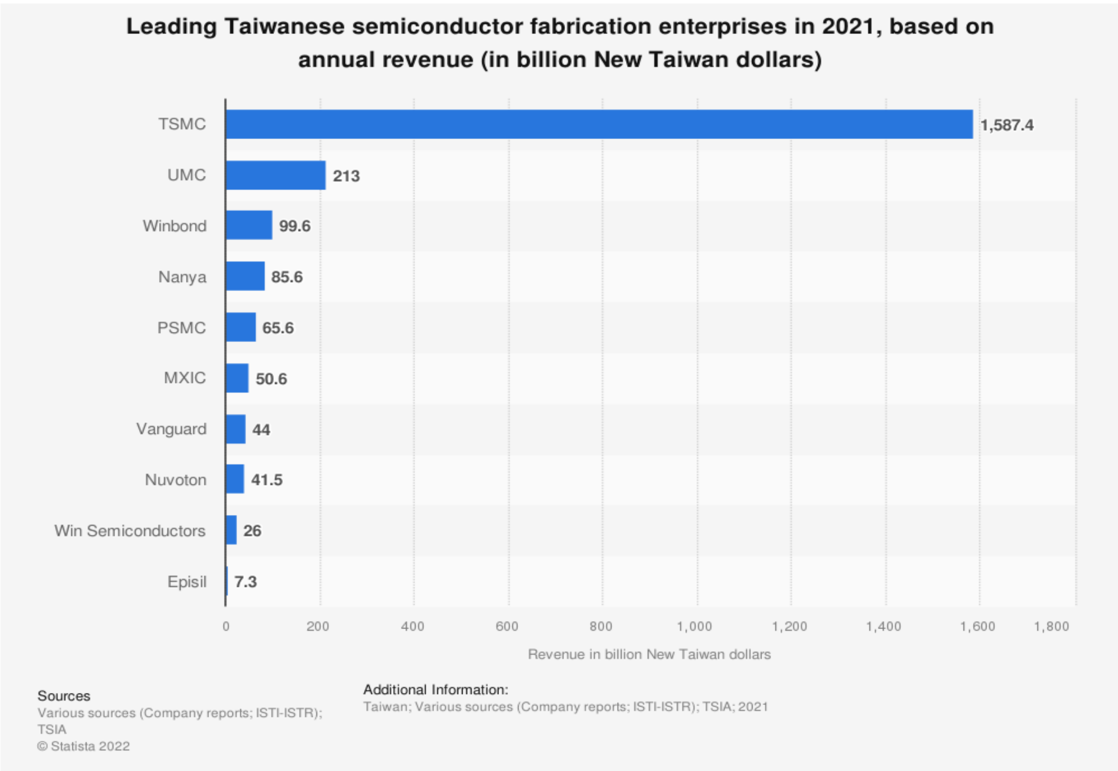
Source: [50]

Exhibit 12. Distribution of semiconductor sales worldwide from 2015 to 2020, by region



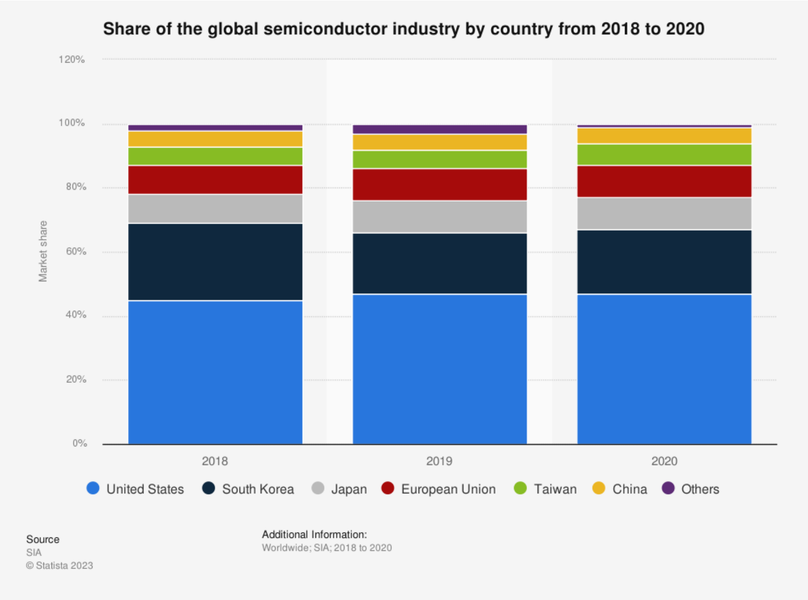
Source: [51]

Exhibit 13. Leading Taiwanese semiconductor fabrication enterprises in 2021, based on annual revenue



Source: [52]

Exhibit 14. Share of the global semiconductor industry by country from 2018 to 2022



Source: [49]

Exhibit 15. Taiwan's semiconductor enterprises, employment, revenue & labor compensation as a percentage of total (2016)

Taiwan	No. Enterprises	No. Persons Employed	Revenue NTD (New Taiwan Dollar)	Labor Compensation NTD (New Taiwan Dollar)
Total	1,296,304	8,830,013	60,583,378,910	5,596,143,626
Semiconductor	712	266,025	2,579,676,616	329,644,702
% of total	0.05%	3.01%	4.26%	5.89%

Source: [25]

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